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ASD-TDR-63-846

AD-613 040

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SURVEY OF THE THERMOCHEMISTRY OF HIGH-ENERGY REACTIONS

TECHNICAL DOCUMENTARY REPORT NO. ASD-TDR-63-846
August 1963

AF Avionics Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Project No. 4040, Task No. 404003

(Prepared under Contract No. AF 33(616)-7835
by the IIT Research Institute, Chicago, Ill.,
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FOREWORD

This report, Technical Report No. IITRI-C191-33, describes the thermodynamic and computational phases of a research program entitled "Study of New Materials Related to the Development of Radiant and Thermal Sources." The report covers the period from April 15, 1962, to August 14, 1963. The investigation was conducted at the IIT Research Institute and its predecessor organization, Armour Research Foundation, Technology Center, Chicago 16, Illinois, under the sponsorship of the Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Mr. Jason W. Sarnow of the AF Avionics Laboratory served as Project Engineer. The work was performed under Contract AF 33(616)-7835 (IITRI Project C191).

Dr. Sidney Katz, Scientific Advisor, was the Project Leader. Dr. Elliott Raisen served as Group Leader of Thermochemistry and as Task Supervisor. Administrative direction was provided by Dr. J. I. Bregman, Assistant Director of Chemistry Research. Other participants in the work include Paul Ase, Robert H. Boes, Karl Franson, Richard Snow, Betty Isakson, Pat Llewellen, Roberta Patzer, Loretta Lucek, Gertrud Matuschkovitz, and Martha Williams.

ABSTRACT

SURVEY OF THE THERMOCHEMISTRY OF HIGH-ENERGY REACTIONS

This report describes the thermodynamic and computational phases of a survey of exothermic chemical reactions. The purpose of the survey was to ascertain the utility of these chemical reactions as radiation sources for a variety of applications.

All currently available thermochemical data were surveyed. Computer programs were prepared and enthalpies were obtained for all inorganic reactions for which data were adequate. Tabulations included reactions of metals with oxides, fluorides, chlorides, sulfides, phosphides, azides, nitrides, silicides, carbides, nitrates, nitrites, chlorates, perchlorates, chromates, and borides. Data for a total of about 20,000 reactions were obtained. The data for the individual reactions included a balanced chemical equation, and enthalpies and heats of reaction per unit weight and volume. Supplementary tabulations included listings in order of energies of the most energetic reactions in each class, graphical presentations of the reactions of all the metals with various oxidizing agents plotted against enthalpies, similar plots for the reactions of all the oxidants in different classes with various metals, and a total recapitulation of all the reactions in each category in grid form in descending order of energy per unit weight and per unit volume. An extension of this survey to include the detection of the free energies of the reactions is proposed.

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SURVEY OF THE THERMOCHEMISTRY OF HIGH-ENERGY REACTIONS

I. INTRODUCTION

The use of pyrotechnic reactions for the production of radiant and thermal energy has generated an interest in high-energy reactions in this laboratory. As a result, we have been conducting theoretical and experimental studies of high-energy reactions for the past several years. The theoretical studies were concerned with systematic examination of the reactions of metals with different oxidizer systems in order to establish logical criteria for choosing reactions to be studied experimentally. The experimental phases were concerned with the chemical and radiative properties of the reactions and included manipulative studies to establish control over the burning properties of the reactions, calorimetric studies to compare experimental enthalpies with theoretical values, burning-rate studies as a function of the ambient atmosphere, differential thermal analysis and thermogravimetric studies to aid in the interpretation of the kinetics and mechanisms of the reactions, and studies of the spectroradiative properties in the visible and infrared regions of the spectrum.

The most important property of the reaction is its enthalpy, which determines the maximum amount of heat available after the reaction occurs. If the reaction is carried out adiabatically, this heat will raise the temperature of the products to a value which is determined by their specific heats. If the reaction is carried out isothermally, the thermal energy can be used for processes involving energy absorption. The reactions exhibiting high negative enthalpies were therefore of most interest.

Much of the present study was concerned with calculating reaction enthalpies and correlating them with the properties of the reactants and the products and with relationships in the periodic table. The periodic table and the rapidly increasing body of thermochemical data on heat capacities, entropies, and heats and free energies of formation provide a framework for examining and correlating the theoretical behavior of thermochemical reactions. For our practical purposes it was most useful to compare the energy content of the reactions on a volumetric basis, because most of our applications are volume-limited. Since weight limitations are important too, the gravimetric enthalpies were also determined.

Manuscript released by authors in August 1963 for publication as an ASD Technical Documentary Report.

II. SCOPE OF THE STUDY

A. Reactions Surveyed

In earlier work 2600 reactions of metals with binary oxides and 50 reactions of metals with fluorides were examined by using manual computations. On the present program 60,000 high-energy reactions were examined by using a Remington-Rand Univac 1105 computer. Of these, about 20,000 reactions were printed by the computer and 10,000 of them were stored on magnetic tape for further operations. The remaining reactions were discarded either because they had positive enthalpies or because other reactions between the same reactants were found with greater negative enthalpy. In chlorate reactions, for example, eac set of reactants may undergo several different stoichiometric reactions to produce different combinations of oxides and chlorides of the constituent metals.

The scope of the theoretical survey is summarized in Table 1. Sixteen classes of oxidizer systems were examined. The data for oxides, fluorides, and chlorides were the most numerous, being represented by 145, 105, and 102 compounds each. The others ranged from 68 for the sulfides to 5 for the chromates. The possible reactions of all these oxidizers with as many as 68 metals were examined.

The data compiled for the oxides were also used in the calculations involving ternary oxidants such as the nitrates, nitrites, chlorates, and perchlorates, in which oxides occur as a product. All the oxide reactions were examined by use of the computer to produce a more complete set of such reactions than those calculated previously; over 20,000 reactions were examined in 6 hours. It is estimated that the same task would take about 1 hour by using an IBM 7090 computer and about 7 man-years by using manual methods.

In general, the perchlorates, chlorates, oxides, and nitrates are the most energetic classes of reactions, followed by the fluorides, nitrites, silicides, nitrides, sulfides, and carbides. The enthalpy of the most energetic reaction in each of these classes is listed in Table 2. The results of this survey were used as a guide in choosing reactions to be studied in the laboratory.

Table 1

SCOPE AND SUMMARY OF THEORETICAL SURVEY
OF THERMOCHEMICAL REACTIONS

Oxidizer Class	Number of Oxidizers	Number of Reactions Examined	Number of Reactions Printed	Enthalpy of the Most Energetic Reactions, cal/cc
Oxides	145*	20,994	9,636	-8279 to -4949
Fluorides	105	n.r.	105	-5586 to -3000
Chlorides	102	10,545	3,061	-3336 to -2593
Sulfides	68	n.r.	2,145	-3169 to -2553
Nitrides Azides	44 13	n.r.	1,575	-2478 to -1766 -3346 to -1795
Silicides	36	n.r.	302	-5153 to -480
Carbides	30	n.r.	386	-2532 to -1102
Nitrates Nitrites	18 8	n.r.	1,226	-7798 to -3468 -4670 to -3476
Phosphides	25	n.r.	500	-1254 to -18
Chlorates Perchlorates	7 9	16,384	800	-7853 to -6100 -9459 to -6099
Borides	8	n.r.	14	-2994 to -110
Chromates	5	2,920	114	-3845 to -1915
Organic fluorides	Examined on a limited basis manually			

*The data for 71 oxides were used in the nitrate and nitrite computations.

n.r. Not recorded.

Table 2

THE MOST ENERGETIC REACTION IN TERMS
OF VOLUMETRIC ENTHALPY IN EACH CLASS OF OXIDIZERS

Class	Reaction	Enthalpy, cal/cc
Perchlorates	$8Be + MgClO_4 = MgCl_2 + 8BeO$	-9459
Chlorates	$13Be + 4\ AgClO_3 = 2Ag_2Cl + 12BeO + BeCl_2$	-8103
Oxides	$2Be + RuO_2 = Ru + 2BeO$	-8279
Nitrates	$5Be + 2LiNO_3 = LiO + 5BeO + N_2$	-7798
Fluorides	$3Be + ReF_6 = Re + 3BeF_2$	-5586
Nitrites	$3Be + 2NaNO_2 = Na_2O + 3BeO + N_2$	-4670
Silicides	$3CoSi_2 + 2Ba = 3Co + 2BaSi_3$	-5153
Chromates	$4Be + 2PbCrO_4 = Pb_2O + 4BeO + Cr_2O_3$	-3845
Azides	$9Be + BaN_6^{*} = Ba + 3BeN_2$	-3346
Nitrides	$2U + 3Fe_2N = 6Fe + U_2N_3$	-2478
Chlorides	$5Ce + ReCl_5 = 3Re + 5CeCl_3$	-3336
Sulfides	$8Th + 7FeS_2 = 7Fe + 2Th_4S_7$	-3169
Carbides	$2Ta + Li_2C_2 = 2Li + 2TaC$	-253[illegible]

*N_6 represents $(N_3)_2$

B. Computer Input and Output

All the data used for the computer input were obtained from the sources shown in Table 3 in the order of preference indicated. The National Bureau of Standards Circular 500[1] was used as the primary source whenever possible. In all cases, the heat of formation at 298°K was used.

Table 3

SOURCES OF DATA FOR THERMOCHEMICAL REACTIONS

Property	Source, in Order of Preference
Heat of formation at 298°K (ΔH_{298})	Reference 1, 2, 4, 5
Molecular weight	Reference 5
Density	Reference 5
Melting point	Reference 1, 3, 5
Boiling point	Reference 1, 3, 5

[1] Rossini, F. D., Wagman, D. D., Evans, W. H., and Levine, S. Selected Values of Thermodynamic Tables, National Bureau of Standards Circular 500, 1952.

[2] Glassner, A. The Thermochemical Properties of Oxides. Fluorides and Chlorides to 2500°K, Argonne National Laboratories, No. 5750, 1957.

[3] Hodgman, C. D., ed., Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., Cleveland, 1954-55.

[4] Quill, L. L., ed., The Chemistry and Metallurgy of Miscellaneous Materials, Thermodynamics, McGraw-Hill Book Co., 1950.

[5] Hodgman, C. D., ed., Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., Cleveland, 1960-61.

The input data consisted of the reactants and products, their heats of formation, and various of their physical properties: molecular weight, melting point, boiling point, and density. Computer programs were designed which combined all the reducing agents (metals) and oxidizers (oxides, chlorides, perchlorates, etc.) into balanced equations and calculated the enthalpy of the stoichiometric reaction. Reactions with positive enthalpies were discarded. Those with negative enthalpies were subjected to further computations to determine the gravimetric and volumetric enthalpies* based on the reactants' weight and volume. Then each reaction was printed together with the data for each component. This output was stored on magnetic tape for the further processing discussed later.

Much of the input data was printed, so that all the properties for each reaction were conveniently assembled in one place. Melting points and boiling points aid in determining practical uses for the reactions. Physical states of the reactants aid in determining the feasibility of formulating and storing the materials. Melting points and boiling points of the products indicate potentially useful properties of the reactions. For example, if the products undergo a phase transition at the temperature of maximum radiative energy, the reaction products will tend to liberate more of their energy at this temperature and thus increase the efficiency. Also, if gaseous products are desired for radiative or other purposes, reactions that have relatively low-boiling products can be selected. Conversely, if solid products are desired, reactions that have high-melting products can be selected. Assembling the input and calculated data in one place thus increases the versatility of the compilations.

The output consisted of the following input and derived data: a balanced equation, the reaction components, heats of formation at 298°K, the averaged densities of the components, the melting points of the components, the boiling points of the components, heat of the reaction on a molar basis, the reactants' averaged density, the heat of the reaction per unit weight of the reactants (the gravimetric enthalpy), the heat of the reaction per unit volume of reactants (the volumetric enthalpy), and the atomic numbers of the components. Output values were omitted when the data were too limited to allow the required calculation. For example, if the reactant density was unknown, the position for volumetric enthalpy was blank.

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*In this work the "volumetric enthalpy" is used to designate the heat of the reaction based on a stoichiometric mixture of reactants occupying a theoretical volume of 1 cc. Similarly, the gravimetric enthalpy is the corresponding heat of reaction based on a gram of reactants.

C. Theory

A generalized equation for the reactions of a metal with a binary compound is:

$$z\,A + y\,B_xC_w \longrightarrow x\,y\,B + A_zC_{yw} \qquad (1)$$

where A and B are electropositive elements (metals); C is an electronegative element (O, F, Cl, S, C, B, N, H, etc.); and z, y, x, and w are the constants for the stoichiometric reaction after the coefficient of the last term is adjusted to unity. The metal A reduces the compound B_xC_w to form the metal B and the compound of metal A. In order to calculate the energy per unit volume of reactants, the following equation is derived:

$$\Delta H_{cc} = -\frac{\Delta H_{A_zC_{yw}} - y\,\Delta H_{B_xC_w}}{z\,V_A + y\,V_{B_xC_w}} = \frac{\Delta H_{AO_x} - y\,\Delta H_{BO_x}}{z\,V_A + y\,V_{BO_x}} \qquad (2)$$

where ΔH_{cc} is the heat of reaction per unit volume of reactants; V is the gram-atomic and gram-molecular volume of the respective reactants, i.e., the atomic or molecular weight divided by the density; and

$$\Delta H_{AO_x} \text{ and } \Delta H_{BO_x}$$

are the molar heats of formation of the products and the reactants, respectively.

To obtain a large energy per unit volume of reactants, it is evident that the heat of formation of the products

$$\Delta H_{A_zC_{yw}}$$

should be large, the heat of formation of reactants

$$\Delta H_{B_xC_w}$$

and the gram-atomic and the gram-molecular volumes of the reactants

$$V_A \text{ and } V_{B_xC_w}$$

should be small, and the coefficients y and z should also be small. According to the usual convention, a negative ΔH is considered as energy output. Thus, in this analysis a "large"

$$\Delta H_{A_zC_{yw}}$$

in reality signifies a large negative number and a "small"

$$\Delta H_{B_xC_w}$$

signifies a small negative number or even a positive number; hence a large negative value for $\Delta H/cc$ is desired.

The use of Equation 2 can be demonstrated by examples from the oxide systems. In general, the oxide of the reducing agent should have a heat of formation

$$\Delta H_{A_zC_{yw}}$$

exceeding -250 kcal and the reducing agent itself a gram-atomic volume less than 15 cc, while the oxidizing agent should have a heat of formation

$$\Delta H_{B_xC_w}$$

less than 100 kcal and a gram-molecular volume less than 35 cc. If the components of a reaction satisfy these four conditions, the reaction will be highly energetic, except when the combination of valences produces large values of y and z which nullify the other factors. The y term is especially significant because of its influence on the numerator. The value of y is not a constant for an oxide but is rather a function of the valence of element A in the reaction, and it can only be found by balancing the reaction and adjusting the coefficient of the A_zC_{yw} term to unity. Various exceptions occur when one of the four factors is outside the specified range, but the extreme value of one or more of the other factors compensates.

The reducing agents Be, Mg, La, and Nd and the oxidizing agents WO_3, Fe_2O_3, OsO_4, and Tl_2O_3 are examples of the various possibilities. For example, the low gram-atomic volumes of Be and Mg (4.96 and 14.0 cc, respectively) compensate for the rather low heats of formation of their oxides (-146.0 and -148.9 kcal, respectively), while the large heats of formation of the oxides of La and Nd (-433 and -436 kcal, respectively) compensate for the high gram-atomic volumes of the metals (50 and 46 cc, respectively). Similarly, the low gram-molecular volumes of WO_3 and Fe_2O_3 compensate for their rather high heats of formation. On the other hand, the low heats of formation of OsO_4 and TlO_3 (-93.6 and -84 kcal, respectively) compensate for their relatively large gram-molecular volumes (51.8 and 44.8 cc, respectively).

D. Presentation of Data

Initially the computer was programmed to take each metal-oxidizer compound in alphabetical order and to treat it as the product of the reaction. When the oxidized metal exists in several valence states, each state was treated as a separate compound. All the other compounds were taken successively in alphabetical order and treated as reactants. A balanced equation was computed by using the appropriate metal from each of the compounds in the reaction. The enthalpy of the reaction was then computed by taking into account the coefficients in the balanced equation. If the enthalpy was negative, the gravimetric and volumetric* enthalpies were calculated and all the data for each reaction were printed. If the enthalpy was positive, the reaction was ignored** and the program went on alphabetically to the next compound. This was done for each metal. Later the order of choosing reactions was based on the reactant oxidizer.

Thus all the reactions of one metal with a series of reactants which yield the same product were printed. When the product exists in a higher valence form, the same process was repeated for the higher valence form. Then the next product was treated in alphabetical order. This type of output, represented by 1 in Table 4, was printed and also stored on magnetic tape. In order to make the data more readily available, the magnetic tape was processed many times with different programs to produce the other types of outputs shown in Table 4. These outputs all contain essentially the same data but arranged in different formats. All the outputs were obtained on volumetric and gravimetric bases.

It would be impractical to reproduce the prodigious amount of material available from the computer. The results are summarized and discussed in this report, and representative data sheets for each type of oxidizer system are included for illustrative purposes.

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*The volumetric enthalpies were calculated from the density of condensed phases only.

**Reactions with positive enthalpies are not of interest here. If they were included, twice as many reactions would result.

Table 4

TYPES OF COMPUTER OUTPUTS

Oxidizer Classes Programmed	Type	Description	Purpose
Oxides Fluorides Chlorides Sulfides Nitrides Azides Silicides Carbides Nitrates Nitrites Phosphides Chlorates Perchlorates Borides Chromates	1	Compilation of balanced equations together with input and output data for each constituent.	Summarize all the data for each reaction in one place.
Oxides Chlorides Chlorates Perchlorates Chromates	2	A list of all the reactions for each system in order of decreasing negative values of gravimetric enthalpy.	Rapid determination of the most energetic reactions of each oxidizer class on a gravimetric basis. This indicates the maximum energy for a unit weight of reactants.
Oxides Fluorides Chlorides Sulfides Nitrides Azides Silicides Carbides Nitrates Nitrites Phosphides Chlorates Perchlorates Borides Chromates	3	A list of all the reactions for each system in order of decreasing negative values of volumetric enthalpy.	Rapid determination of the most energetic reactions of each oxidizer class on a volumetric basis. This indicates the maximum energy for a unit volume of reactants.

Table 4 (cont.)

Oxidizer Classes Programmed	Type	Description	Purpose
Oxides Chlorides Chlorates Perchlorates Chromates	4	A list of all the data used for the graphs. Graphs of the gravimetric enthalpy of one metal versus the oxidizers for each metal.	Helpful in finding the best oxidizer with a particular metal or for examining the periodic behavior of a metal with the different oxidizers, based on a unit weight of reactants.
Oxides Nitrates Chlorides Chlorates Perchlorates Chromates	5	A list of all the data used for the graphs. Graphs of the volumetric enthalpy of one metal versus the oxidizers for each metal.	Helpful in finding the best oxidizer with a particular metal or for examining the periodic behavior of a metal with each oxidizer, based on a unit volume of reactants.
Oxides Chlorides Chlorates Perchlorates Chromates	6	A list of all the data used for the graphs. Graphs of the gravimetric enthalpy of one oxidizer versus the metals for each oxidizer.	Helpful in finding the best metal for a particular oxidizer, or for examining the periodic behavior of an oxidizer with the different metals, based on a unit weight of reactants.
Oxides Chlorides Chlorates Perchlorates Chromates	7	A list of all the data used for the graphs. Graphs of the volumetric enthalpy of one oxidizer versus the metals for each oxidizer.	Helpful in finding the best metal for a particular oxidizer, or for examining the periodic behavior of an oxidizer with the different metals, based on a unit volume of reactants.
Oxides Chlorides Chlorates Perchlorates Chromates	8	A chart of the gravimetric enthalpies of all the reactions for each system listed in general descending order from left to right, and from top to bottom.	The most concise summary of the enthalpies of all the reactions of each class. This table indicates the most energetic metals and oxidizers at a glance, based on a unit weight of reactants.
Oxides Chlorides Chlorates Perchlorates Chromates	9	A chart of the volumetric enthalpies of all the reactions for each system listed in general descending order from left to right, and from top to bottom.	The most concise summary of the enthalpies of all the reactions of each class. This table indicates the most energetic metals and oxidizers at a glance, based on a unit volume of reactants.

III. DISCUSSION OF THERMOCHEMICAL DATA

A. Fluoride Reactions

The molecular, gravimetric, and volumetric enthalpies of about 5000 reactions resulting from the combination of 50 metals with 105 fluorides were calculated and compiled on the computer. The reactions of beryllium with cobalt trifluoride, ferric fluoride, and stannic fluoride are particularly energetic; beryllium fluoride is formed in these reactions.

Table 5 is a list of fluoride reactions with negative enthalpies in excess of -3000 cal. The reactions are all of the form:

$$A + BF = B + AF$$

where BF and AF are the reactant and product fluorides, respectively, and A and B are the corresponding metals. Each reaction is identified by the reactant and product fluoride and their molecular coefficient; the metal reactants and products are omitted from the tabulation.

As a group, the fluorides are a highly energetic series of reactions. Experimental study of many of these reactions should prove interesting, especially those with very high enthalpies and those with products that have low melting or low boiling points. The reactions with the following products merit further study: mercury, cobalt, tin, iron, silver, bismuth, antimony, manganese, nickel, gallium, cadmium, chromium, beryllium fluoride, germanium fluoride, neodymium fluoride, praseodymium fluoride, and lithium fluoride.

Figure 1 illustrates the periodic behavior of the enthalpies of the fluoride reactions. The metals are plotted by atomic number along the abscissa, and the volumetric enthalpies of their reactions with cobalt trifluoride are shown on the ordinate. Cobalt fluoride was chosen as the reactant because most of its reactions are highly energetic. A representative reaction is:

$$3Be + 2CoF_3 = 2Co + 3BeF_2; \qquad \Delta H = -380.2 \text{ kcal}$$

Here, ΔH is the molar enthalpy. The enthalpy in Table 5 is the heat of the reaction on a volumetric basis in terms of calories per cubic centimeter of reacting material, in this case -5111 cal/cc.

All the available data are plotted in Figure 1, and the various points are connected by solid, dotted, or dashed lines to indicate their relationships within the periodic table. The solid lines connect metals with adjacent atomic numbers, the dotted lines connect members of the same group, and the dashed

lines connect the members of a B group (transition metals). The three subfigures 1A, B, and C emphasize each of these relationships.

Figure 1A, in which the adjacent atomic numbers are connected, illustrates the overall periodic behavior of the enthalpies. In general, the Group II elements (beryllium, magnesium, calcium, strontium, and barium) establish the peaks in the energy outputs (i.e., the largest negative enthalpies) and the Group I elements (lithium, sodium, potassium, rubidium, and cesium) establish the minima. The curve is irregular in the neighborhood of strontium and barium because the Group IIIB metals (yttrium, lanthanum, and the rare earths) and the Group IVB metals (titanium, zirconium, and hafnium) have unusually small atomic volumes and their fluorides have relatively high heats of formation.

The elements establishing the peaks in the energy curve are characterized by one or more of the following:

> The electronic configuration of their valence orbitals. Their outermost orbital has two electrons, and the next-to-outermost orbital has either one or two electrons.
>
> Their electronic configuration in the fluorides. They all have the rare gas configuration, s^2 or s^2p^6.
>
> The high heat of formation of the fluoride relative to the fluoride of their nearest neighbors.
>
> Their low gram-atomic volumes.

Groups IIIB and IVB tend to react more energetically than Group II. The fluoride curve is similar to the analogous oxide and nitrate curves, with a few exceptions. Aluminum, for instance, is less energetic than magnesium in the fluoride system and more energetic in the oxygen system, because of the unusually high heat of formation of the oxide.

The relationship of the elements within Groups IA, IIA, IIIA, and IVA is shown in Figure 1B. Except for boron in Group IIIA, the energies of the reactions of cobalt trifluoride within the elements of a group diminish with increasing atomic number. A group relationship is also apparent. In decreasing order of energy, they follow the sequence Group IIA, IIIA, IVA, and IA.

Figure 1C shows the relationship of the elements within the transition metal groups. Groups IIB (zinc and cadmium), VB (vanadium, niobium, and tantalum), and VIB (chromium, molybdenum and tungsten) are similar to Groups IA, IIA, IIIA, and IVA in that the energy tends to decrease with increasing

Table 5

FLUORIDE REACTIONS* WITH HIGHEST NEGATIVE ENTHALPIES

Enthalpy, cal/cc	Reactant	Product	Metal m.p., °C	Metal b.p., °C	Fluoride m.p., °C	Fluoride b.p., °C
-5586	ReF_6	3 BeF_2	3147		800	
-5206	CF_4	2 BeF_2	4400			
-5112	2 CoF_3	3 BeF_2	1493	3100		
-5015	ReF_6	3 YF_3				
-4960	HgF_2	BeF_2	-39	357		
-4926	ReF_6	2 CeF_3			1460	
-4870	ReF_6	2 LaF_3				
-4830	SnF_4	2 BeF_2	232	2337		
-4820	ReF_6	2 NdF_3			1410	
-4809	ReF_6	2 PrF_3			1370	
-4765	NbF_5	5 BeF_2				
-4683	3 CF_4	4 YF_3				
-4648	FeF_2	BeF_2	1535	2800		
-4603	AgF_2	BeF_2	961	2193		
-4563	CoF_3	YF_3				
-4534	3 HgF_2	2 YF_3				
-4527	3 CF_4	4 LaF_3				
-4460	CoF_3	LaF_3				
-4450	3 HgF_2	2 LaF_3				
-4342	3 SnF_4	4 YF_3				
-4272	3 NbF_3	5 YF_3	2478	3700		
-4268	3 AgF_2	2 YF_3				
-4267	3 SnF_4	4 LaF_3				
-4216	3 AgF_2	2 LaF_2				
-4213	3 FeF_2	2 YF_3				
-4202	3 NbF_5	5 LaF_3				
-4156	3 FeF_2	2 LaF_3				
-3889	BiF_3	YF_3	271	1420		
-3869	BiF_3	LaF_3				
-3821	2 SbF_5	5 BeF_2	630	1440		
-3707	2 TaF_5	5 BeF_2				

Table 5 (cont.)

Enthalpy, cal/cc	Reactant	Product	Metal m.p., °C	Metal b.p., °C	Fluoride m.p., °C	Fluoride b.p., °C
-3704	2 VF_5	5 BeF_2	1730	3000		
-3611	AgF_2	2 LiF			845	1681
-3601	3 SbF_5	5 LaF_3				
-3601	MoF_6	3 BeF_2	2610	4800		
-3589	3 SbF_5	5 BeF_2				
-3573	2 MnF_3	3 BeF_2	1244	2087		
-3568	NiF_2	BeF_2	1455	2800		
-3564	3 TaF_5	5 LaF_3				
-3544	3 TaF_5	5 BeF_2				
-3502	3 VF_5	5 LaF_3				
-3478	3 VF_5	5 YF_3				
-3427	MoF_6	2 LaF_3				
-3424	2 GaF_3	3 BeF_3	30	937		
-3394	MoF_6	2 BeF_2				
-3392	VF_4	2 BeF_2				
-3376	MnF_3	LaF_3				
-3323	3 NiF_2	2 YF_3				
-3329	MnF_3	YF_3				
-3322	2 SbF_3	3 BeF_2				
-3320	2 FeF_3	3 BeF_2				
-3259	GaF_3	LaF_3				
-3214	SbF_3	LaF_3				
-3202	FeF_3	LaF_3				
-3192	GaF_3	YF_3				
-3183	3 VF_4	4 BeF_2				
-3157	SbF_3	YF_3				
-3144	3 AgF	LaF_3				
-3143	CdF_2	BeF_2	321	767		
-3109	3 CrF_3	3 BeF_2	1900	2480		
-3098	3 AgF	YF_3				
-3070	3 CdF_2	2 LaF_3				
-3038	3 CrF_3	LaF_3				

*The first reaction, for example, is: 3 Be + ReF_6 = Re + 3 BeF_2.

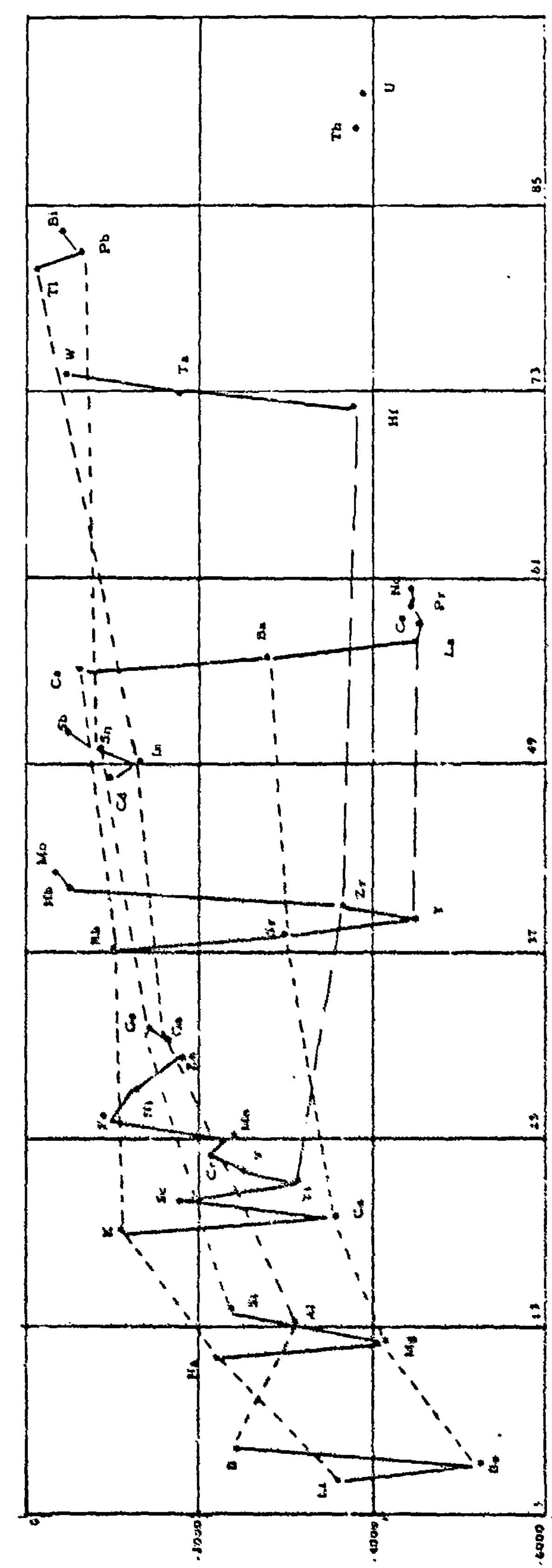


Figure 1

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH CoF_3

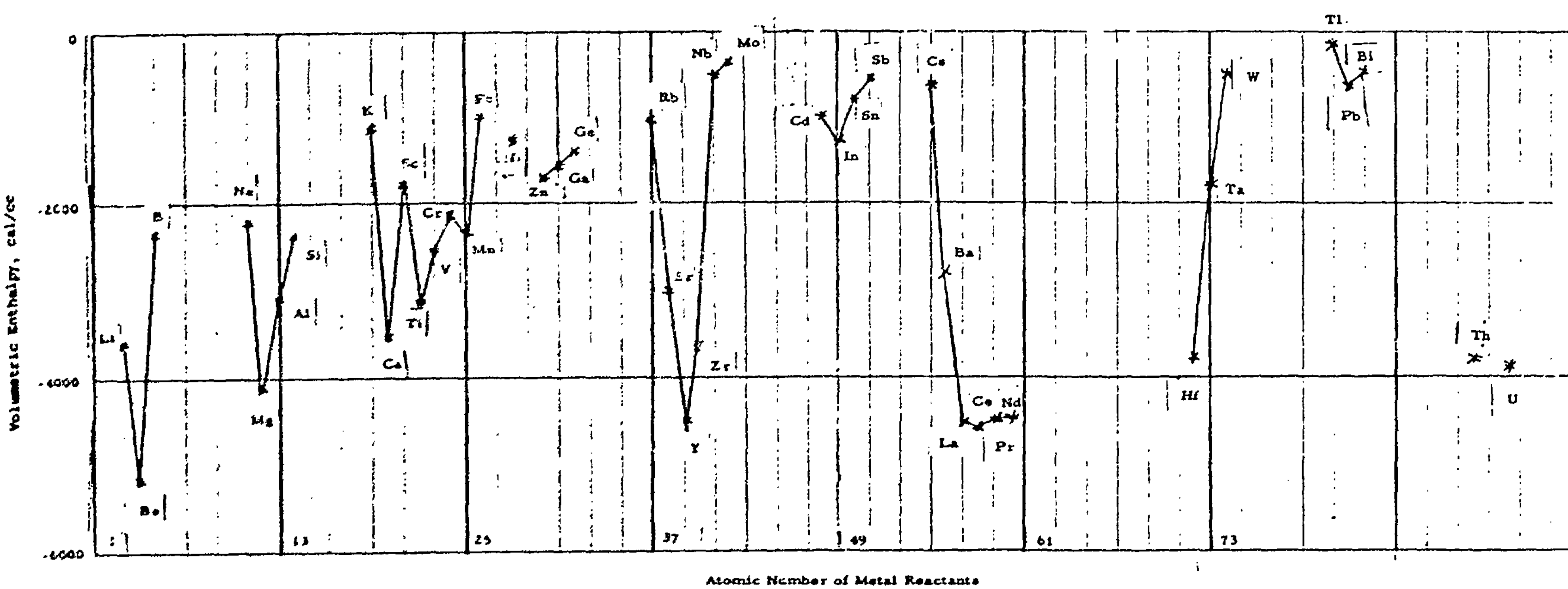
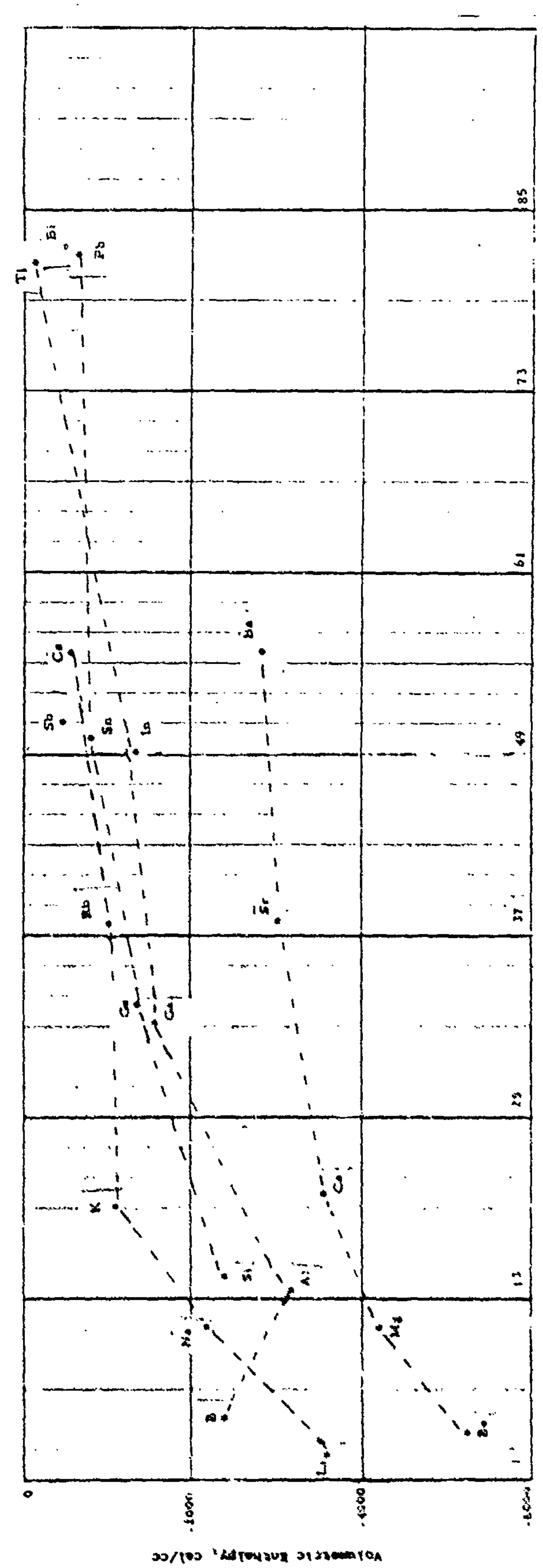


Figure 1A

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH CoF_3



Atomic Number of Metal Reactants

Figure 1a

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH CoF_3

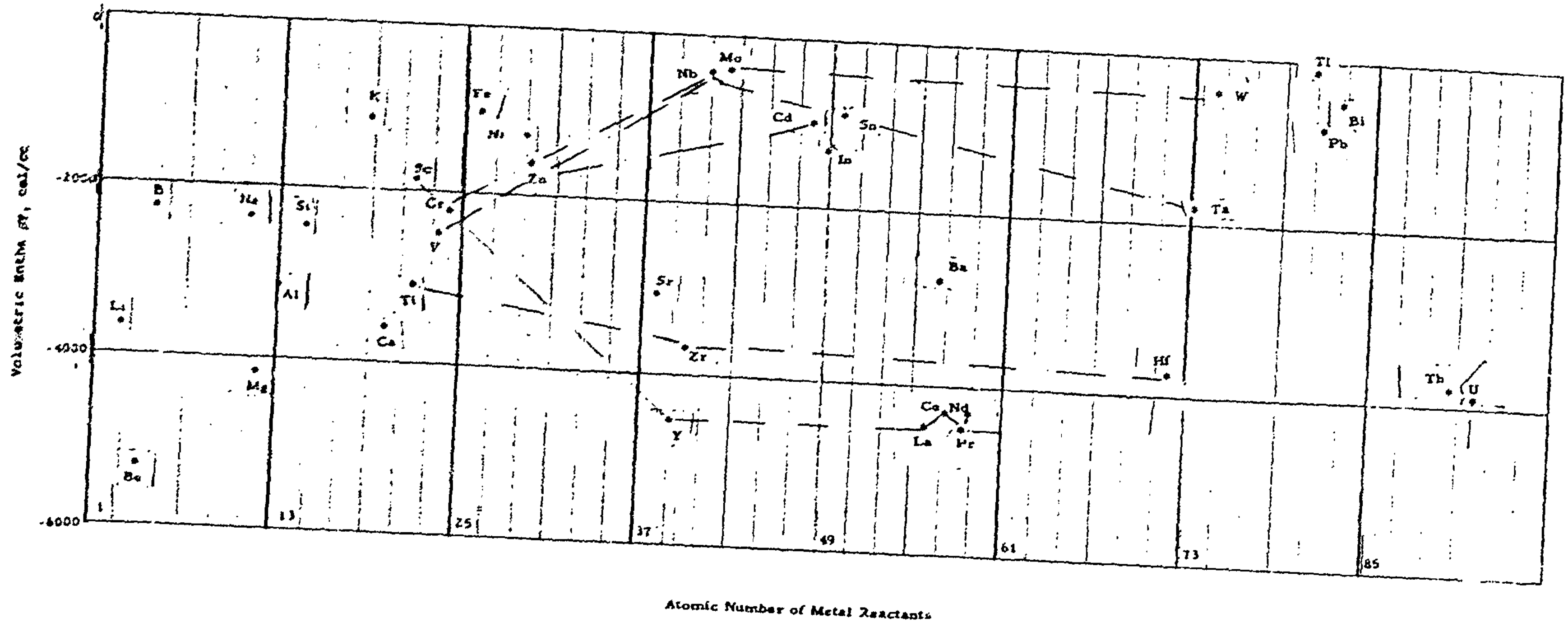


Figure 1C

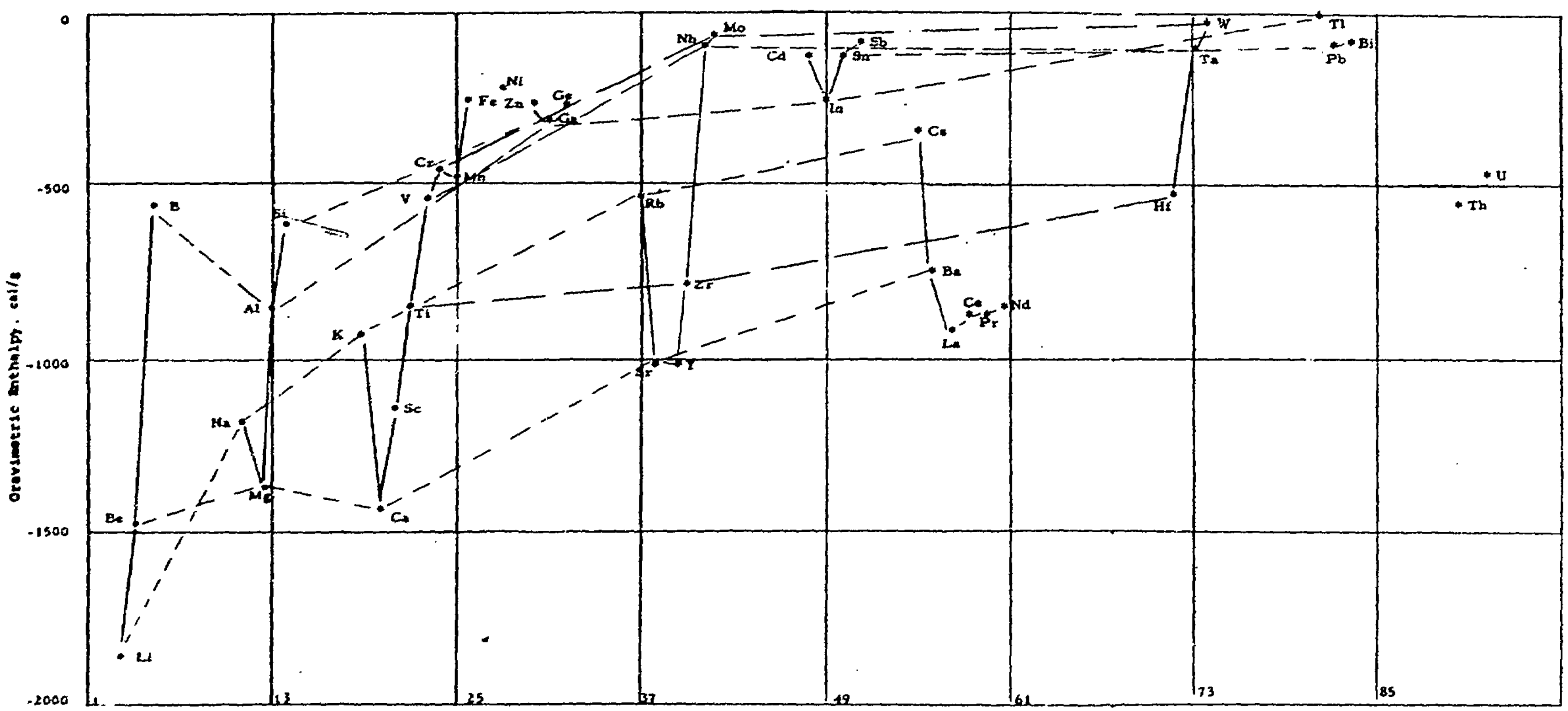
VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH CoF_3

atomic number. Groups IIIB (scandium, yttrium, and lanthanum, and the rare earth elements) and IVB (titanium, zirconium, and hafnium) exhibit the opposite behavior and increase in energy with increasing atomic number. This behavior is due primarily to the small increase, or even decrease, in the atomic volume of the elements in these groups with increasing atomic number, caused by the lanthanide contraction. Groups IIIB and IVB are the most energetic, and Groups IIB, VB, and VIB are the least energetic.

Similar relationships for the gravimetric enthalpies (heat output per gram of reactants) are illustrated in Figure 2. A few differences are observed because densities of the reactants vary. Since the volume is not considered, the effect of the lanthanide contraction is not evident, and Groups IIIB and IVB exhibit a normal behavior, with their energy decreasing with increasing atomic number. On the gravimetric basis, lithium is more energetic than beryllium, scandium more energetic than titanium, and Group I more energetic than Group III. The gravimetric enthalpies are lower than the volumetric ones because the densities of the reactants are more than unity in all cases.

Although the volumetric enthalpies were considered more significant for the present studies, because the establishment of a maximum energy in a fixed volume is usually desired, the gravimetric enthalpies were also considered in choosing the reactions to be studied experimentally. Less information is available on volumetric enthalpies because the densities of the reactants are often not known.

Figures 1 and 2 emphasized the effect of the metal on the enthalpy of the reactions. Figures 3 and 4 emphasize the effect of the fluoride. The volumetric and gravimetric enthalpies of the reactions of the fluorides with beryllium are plotted in Figures 3 and 4 on the ordinate, with the atomic number of the metal in the fluoride shown on the abscissa. A periodic behavior is apparent but is difficult to specify because fluorides of each metal can exist in different valence states. In general, within a group the energy decreases with increasing atomic number; since the metals are in the oxidized form, the order of the groups is reversed. Thus Groups IIIB and IVB are the least energetic when the metal fluoride, rather than the metal, is used as the reactant. Groups V, VI, VII, and VIIIB, represented by vanadium, chromium, manganese, iron, cobalt, molybdenum, tungsten, rhenium, and osmium fluorides, are the most energetic. When a metal forms more than one fluoride, the one with the greatest number of fluorine atoms is usually the most energetic. The iron flurides are exceptions, FeF_2 being more energetic than FeF_3. The trends illustrated in the figures are similar for the other fluorides and metals, except for displacement of the vertical scale



Atomic Number of Metal Reactants

Figure 2

GRAVIMETRIC ENTHALPIES OF REACTIONS OF METALS WITH CoF_3

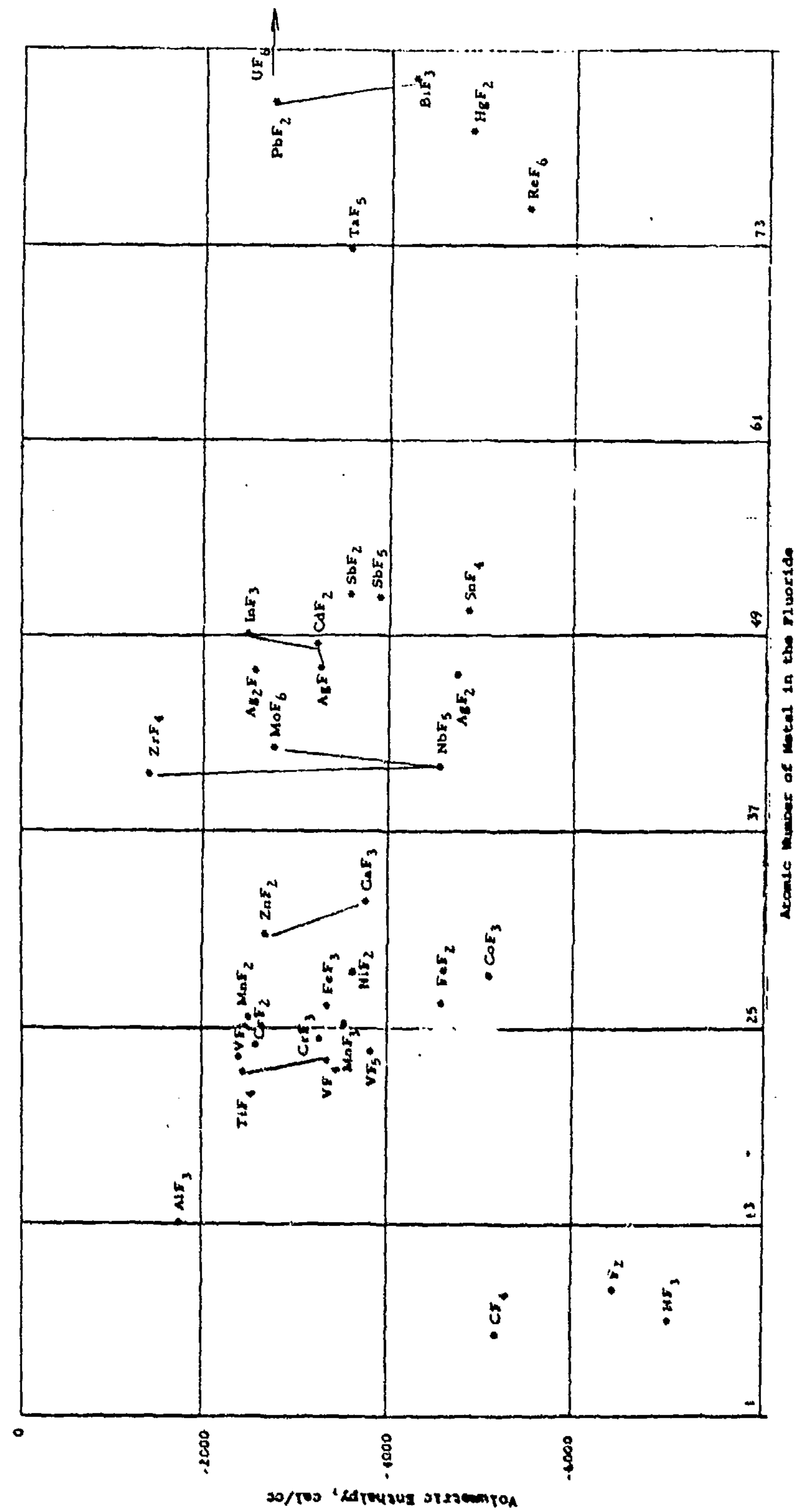
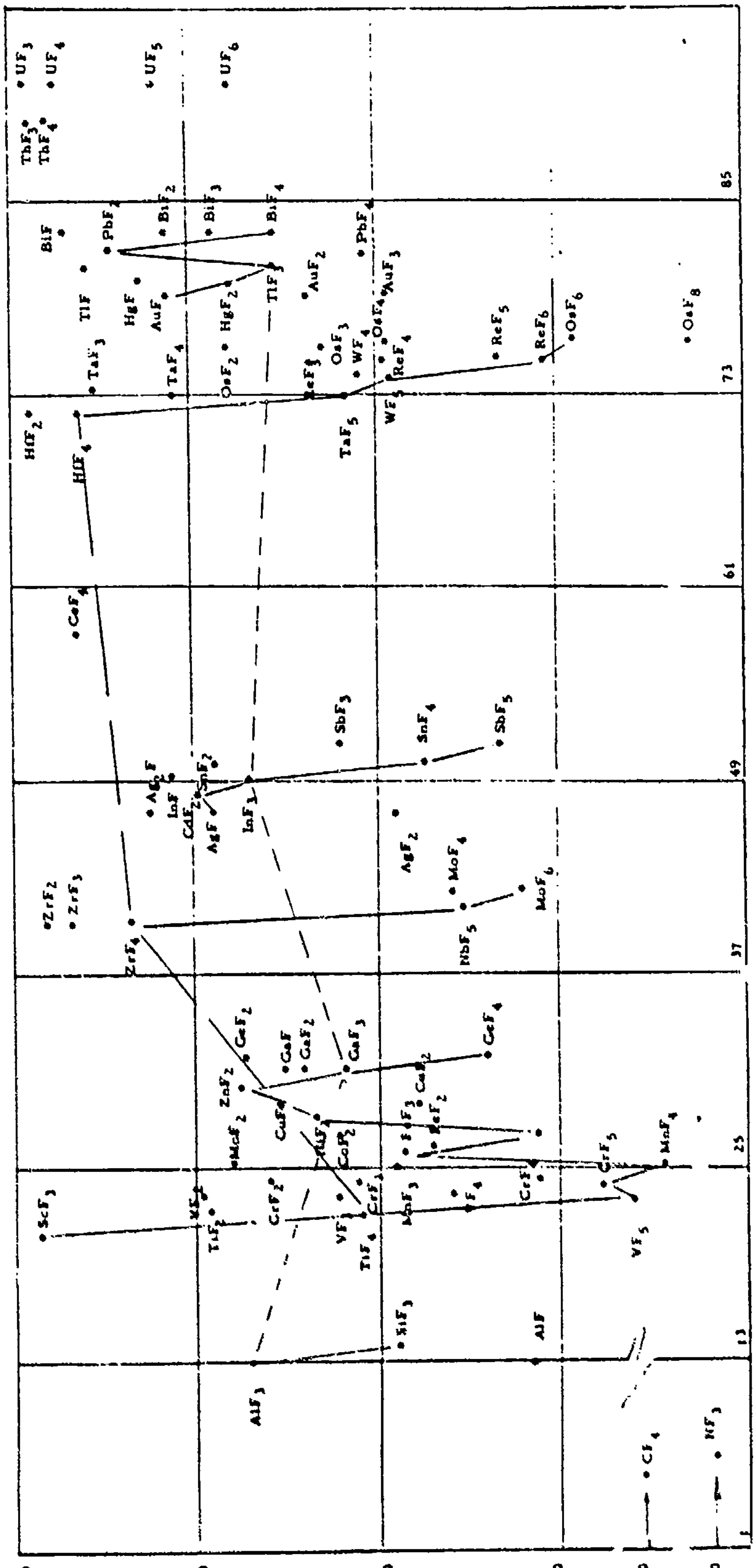


Figure 3

VOLUMETRIC ENTHALPIES OF REACTIONS OF FLUORIDES WITH Be



Atomic Number of Metal in the Fluoride

Figure 4

GRAVIMETRIC ENTHALPIES OF REACTIONS OF FLUORIDES WITH Be

B. Oxide Reactions

A total of 20,994 reactions involving 145 oxides was examined, and the data for 9636 reactions were printed. Of the 9636 reactions, about half were pertinent to the present study; reactions with positive and negative enthalpies were inadvertently included in the output. The oxides form a highly energetic class of reactions, with volumetric enthalpies up to -8279 cal/cc. The oxide systems, including the perchlorates, chlorates, and nitrates, are the most energetic of all the classes of reactions examined. The oxide parameters tend to dominate and, as a result, the trends in perchlorate, chlorate, and nitrate reactions are similar to those in the oxide reactions.

Representative computer outputs, including some of the more energetic reactions, are shown in Table 6. In this format all the data for each reaction are assembled in one place. Several reactions with positive enthalpies are shown. On a molar or gravimetric basis, they are the same as the reverse reaction with a negative enthalpy. On a volumetric basis, the results for the reverse reaction are slightly different, since the reactants and products have different densities. This is illustrated by the reaction of silver with cobalt monoxide and the reverse reaction of cobalt with silver oxide. It is also demonstrated by the fact that the reaction between cobalt and silver oxide is more energetic when the cobalt monoxide, rather than the dicobalt trioxide, is produced. This is not obvious from Table 6 because only the reaction with the greatest thermal output is printed when more than one reaction is possible between any two reactants.

The most energetic oxide reactions are shown in Tables 7 and 8 on volumetric and gravimetric bases, respectively. On the volumetric basis, the best reducing metals are the lower members of Groups IIA and IIIA (beryllium, magnesium, aluminum, and boron), the Group IVB elements (titanium, zirconium, and hafnium), and the IVF and VF elements (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, gadolinium, etc., and thorium and uranium). On the gravimetric basis, the same elements are the best reducing metals, with a few notable exceptions. Lithium is one of the best metals on a gravimetric basis but is very poor on a volumetric basis because of its extremely low density. On the other hand, the extremely high densities of thorium and uranium cause them to be much more effective on a volumetric than on a gravimetric basis.

The most effective oxidizers on a volumetric basis are the oxides of ruthenium, nitrogen, rhenium, sulfur, silver, osmium, selenium, manganese, carbon, cobalt, arsenic, lead, and copper. The most effective oxidizers on a gravimetric basis are the oxides of nitrogen, carbon, sodium, sulfur, ruthenium, molybdenum, indium, potassium, and chromium.

Table 6

DATA ON REACTIONS OF VARIOUS METALS WITH OXIDES

	Cd	+	Ag_2O	=	2 Ag	+	CdO
Heat of formation			-7.31				-60.86
Molecular weight	112.41		231.76		107.87		128.41
Density	8.64		7.14		10.50		8.15
Melting point, °C	320.90		300.00		960.80		900.00
Boiling point, °C	767.00				2193.00		900.00
Heat of reaction, kcal	-53.55						
Reactants' density	7.57						
Gravimetric enthalpy, cal/g	-155.60						
Volumetric enthalpy, cal/cc	-1178.15						

	2 Ce	+	3 Ag_2O	=	8 Ag	+	Ce_2O_3
Heat of formation			-7.31				-435.00
Molecular weight	140.13		231.76		107.87		328.26
Density	6.70		7.14		10.50		6.90
Melting point, °C	775.00		300.00		960.80		1692.00
Boiling point, °C	2900.00				2193.00		
Heat of reaction, kcal	-413.08						
Reactants' density	7.01						
Gravimetric enthalpy, cal/g	-423.44						
Volumetric enthalpy, cal/cc	-2968.24						

	Co	+	Ag_2O	=	2 Ag	+	CoO
Heat of formation			-7.31				-57.20
Molecular weight	58.94		231.76		107.87		74.94
Density	8.90		7.14		10.50		5.70
Melting point, °C	1493.00		300.00		960.80		1800.00
Boiling point, °C	3100.00				2193.00		
Heat of reaction, kcal	-49.89						
Reactants' density	7.44						
Gravimetric enthalpy, cal/g	-171.63						
Volumetric enthalpy, cal/cc	-1277.10						

Table 6 (cont.)

	2 Ag	+	CoO	=	Co	+	Ag_2O
Heat of formation			-57.20				-7.31
Molecular weight	107.87		74.94		58.94		231.76
Density	10.50		5.70		8.90		7.14
Melting point, °C	960.80		1800.00		1493.00		300.00
Boiling point, °C	2193.00				3100.00		
Heat of reaction, kcal	49.89						
Reactants' density	8.63						
Gravimetric enthalpy, cal/g	171.64						
Volumetric enthalpy, cal/cc	1480.77						

	2 Al	+	3 CoO	=	3 Co	+	Al_2O_3
Heat of formation			-57.20				-399.09
Molecular weight	26.98		74.94		58.94		101.94
Density	2.70		5.70		8.90		3.97
Melting point, °C	660.00		1800.00		1493.00		2015.00
Boiling point, °C	2327.00				3100.00		3500.00
Heat of reaction, kcal	-227.49						
Reactants' density	4.69						
Gravimetric enthalpy, cal/g	-816.02						
Volumetric enthalpy, cal/cc	-3828.99						

	2 As	+	3 CoO	=	3 Co	+	As_2O_3
Heat of formation			-57.20				-156.15
Molecular weight	74.92		74.94		58.94		197.82
Density	5.73		5.70		8.90		4.13
Melting point, °C	817.00		1800.00		1493.00		313.00
Boiling point, °C	817.00				3100.00		460.00
Heat of reaction, kcal	15.45						
Reactants' density	5.71						
Gravimetric enthalpy, cal/g	41.24						
Volumetric enthalpy, cal/cc	235.50						

Table 6 (cont.)

	6 Ag	+	Co_2O_3	=	2 Co	+	3 Ag_2O
Heat of formation			-140.00				-7.31
Molecular weight	107.87		165.88		58.94		231.76
Density	10.50		5.18		8.90		7.14
Melting point, °C	960.80		895.00		1493.00		300.00
Boiling point, °C	2193.00				3100.00		
Heat of reaction, kcal	118.08						
Reactants' density	8.68						
Gravimetric enthalpy, cal/g	145.22						
Volumetric enthalpy, cal/cc	1260.69						

	2 Al	+	Co_2O_3	=	2 Co	+	Al_2O_3
Heat of formation			-140.00				-399.09
Molecular weight	26.98		165.88		58.94		101.94
Density	2.70		5.18		8.90		3.97
Melting point, °C	660.00		895.00		1493.00		2015.00
Boiling point, °C	2327.00				3100.00		3500.00
Heat of reaction, kcal	-259.09						
Reactants' density	4.23						
Gravimetric enthalpy, cal/g	-1178.54						
Volumetric enthalpy, cal/cc	-4983.12						

	2 As	+	Co_2O_3	=	2 Co	+	As_2O_3
Heat of formation			-140.00				-156.15
Molecular weight	74.92		165.88		58.94		197.82
Density	5.73		5.18		8.90		4.15
Melting point, °C	817.00		895.00		1493.00		313.00
Boiling point, °C	817.00				3100.00		460.00
Heat of reaction, kcal	-16.15						
Reactants' density	5.43						
Gravimetric enthalpy, cal/g	-51.15						
Volumetric enthalpy, cal/cc	-277.55						

Table 6 (cont.)

	6 Li	+	Co_2O_3	=	2 Co	+	3 Li_2O
Heat of formation			-140.00				-142.40
Molecular weight	6.94		165.88		58.94		29.88
Density	.53		5.18		8.90		2.01
Melting point, °C	180.00		895.00		1493.00		1700.00
Boiling point, °C	1326.00				3100.00		
Heat of reaction, kcal	-287.20						
Reactants' density	1.89						
Gravimetric enthalpy, cal/g	-1383.96						
Volumetric enthalpy, cal/cc	-2610.89						

	3 Mg	+	Co_2O_3	=	2 Co	+	3 MgO
Heat of formation			-140.00				-143.84
Molecular weight	24.32		165.88		58.94		40.32
Density	1.74		5.18		8.90		3.58
Melting point, °C	650.00		895.00		1493.00		2800.00
Boiling point, °C	1120.00				3100.00		
Heat of reaction, kcal	-291.52						
Reactants' density	3.23						
Gravimetric enthalpy, cal/g	-1220.57						
Volumetric enthalpy, cal/cc	-3941.90						

	3 Mn	+	Co_2O_3	=	2 Co	+	3 MnO
Heat of formation			-140.00				-92.00
Molecular weight	54.94		165.88		58.94		70.93
Density	7.20		5.18		8.90		5.43
Melting point, °C	1244.00		895.00		1493.00		1650.00
Boiling point, °C	2087.00				3100.00		
Heat of reaction, kcal	-136.00						
Reactants' density	6.02						
Gravimetric enthalpy, cal/g	-411.25						
Volumetric enthalpy, cal/cc	-2476.56						

Table 6 (cont.)

	4 Ag +	MnO_2 =	Mn +	2 Ag_2O
Heat of formation		-124.50		-7.31
Molecular weight	107.87	86.93	54.94	231.76
Density	10.50	5.03	7.20	7.14
Melting point, °C	960.80	535.00	1244.00	300.00
Boiling point, °C	2193.00		2087.00	
Heat of reaction, kcal	109.89			
Reactants' density	8.88			
Gravimetric enthalpy, cal/g	211.97			
Volumetric enthalpy, cal/cc	1881.95			
	4 Al +	**3 MnO_2 =**	**3 Mn +**	**2 Al_2O_3**
Heat of formation		-124.50		-399.09
Molecular weight	26.98	86.93	54.94	101.94
Density	2.70	5.03	7.20	3.97
Melting point, °C	660.00	535.00	1244.00	2015.00
Boiling point, °C	2327.00		2087.00	3500.00
Heat of reaction, kcal	-424.68			
Reactants' density	4.02			
Gravimetric enthalpy, cal/g	-1151.80			
Volumetric enthalpy, cal/cc	-4624.68			
	4 As +	**3 MnO_2 =**	**3 Mn +**	**2 As_2O_3**
Heat of formation		-124.50		-156.15
Molecular weight	74.92	86.93	54.94	197.82
Density	5.73	5.03	7.20	4.15
Melting point, °C	817.00	535.00	1244.00	313.00
Boiling point, °C	817.00		2087.00	460.00
Heat of reaction, kcal	61.20			
Reactants' density	5.38			
Gravimetric enthalpy, cal/g	109.19			
Volumetric enthalpy, cal/cc	587.24			

Table 6 (cont.)

	2 Be	+	MnO_2	=	Mn	+	2 BeO
Heat of formation			-124.50				-146.00
Molecular weight	9.01		86.93		54.94		25.01
Density	1.85		5.03		7.20		3.01
Melting point, °C	1283.00		535.00		1244.00		2530.00
Boiling point, °C	2970.00				2087.00		3900.00
Heat of reaction, kcal	-167.50						
Reactants' density	3.88						
Gravimetric enthalpy, cal/g	-1595.91						
Volumetric enthalpy, cal/cc	-6194.56						

	4 Bi	+	3 MnO_2	=	3 Mn	+	2 Bi_2O_3
Heat of formation			-124.50				-137.90
Molecular weight	208.99		86.93		54.94		466.00
Density	9.80		5.03		7.20		8.90
Melting point, °C	271.00		535.00		1244.00		820.00
Boiling point, °C	1420.00				2087.00		1890.00
Heat of reaction, kcal	97.70						
Reactants' density	7.99						
Gravimetric enthalpy, cal/g	89.08						
Volumetric enthalpy, cal/cc	712.15						

	C	+	MnO_2	=	Mn	+	CO_2
Heat of formation			-124.50				-94.05
Molecular weight	12.01		86.93		54.94		44.01
Density	2.25		5.03		7.20		1.98
Melting point, °C	25.00		535.00		1244.00		-56.20
Boiling point, °C	4347.00				2087.00		-78.50
Heat of reaction, kcal	30.45						
Reactants' density	4.37						
Gravimetric enthalpy, cal/g	307.76						
Volumetric enthalpy, cal/cc	1345.30						

Table 6 (cont.)

	8 Ag	+	N_2O_4	=	2 N	+	4 Ag_2O
Heat of formation			2.31				-7.31
Molecular weight	107.87		92.00		14.01		231.76
Density	10.50		1.49		.81		7.14
Melting point, °C	960.80		61.60				300.00
Boiling point, °C	2193.00						
Heat of reaction, kcal	-31.53						
Reactants' density	6 64						
Gravimetric enthalpy, cal/g	-33.02						
Volumetric enthalpy, cal/cc	-219.14						

	8 Al	+	3 N_2O_4	=	6 N	+	4 Al_2O_3
Heat of formation			2.31				-399.09
Molecular weight	26.98		92.00		14.01		101.94
Density	2.70		1.49		.81		3.97
Melting point, °C	660.00		61.60				2015.00
Boiling point, °C	2327.00						3500.00
Heat of reaction, kcal	-1603.29						
Reactants' density	1.86						
Gravimetric enthalpy, cal/g	-3259.77						
Volumetric enthalpy, cal/cc	-6050.32						

	8 As	+	3 N_2O_4	=	6 N	+	4 As_2O_3
Heat of formation			2.31				-156.15
Molecular weight	74.92		92.00		14.01		197.82
Density	5.73		1.49		.81		4.15
Melting point, °C	817.00		61.60				313.00
Boiling point, °C	817.00						460.00
Heat of reaction, kcal	-631.53						
Reactants' density	3.02						
Gravimetric enthalply, cal/g	-721.45						
Volumetric enthalpy, cal/cc	-2179.44						

Table 6 (cont.)

	$4\ Be$	+	N_2O_4	=	$2\ N$	+	$4\ BeO$
Heat of formation			2.31				-146.00
Molecular weight	9.01		92.00		14.01		25.01
Density	1.85		1.49		.81		3.01
Melting point, °C	1283.00		61.60				2530.00
Boiling point, °C	2970.00						3900.00
Heat of reaction, kcal	-586.31						
Reactants' density	1.58						
Gravimetric enthalpy, cal/g	-4578.68						
Volumetric enthalpy, cal/cc	-7221.34						

	$8\ Bi$	+	$3\ N_2O_4$	=	$6\ N$	+	$4\ Bi_2O_3$
Heat of formation			2.31				-137.90
Molecular weight	208.99		92.00		14.01		466.00
Density	9.80		1.49		.81		8.90
Melting point, °C	271.00		61.60				280.00
Boiling point, °C	1420.00						1890.00
Heat of reaction, kcal	-558.53						
Reactants' density	5.48						
Gravimetric enthalpy, cal/g	-286.73						
Volumetric enthalpy, cal/cc	-1570.15						

	$2\ C$	+	N_2O_4	=	$2\ N$	+	$2\ CO_2$
Heat of formation			2.31				-94.05
Molecular weight	12.01		92.00		14.01		44.01
Density	2.25		1.49		.81		1.98
Melting point, °C	25.00		61.60				-56.20
Boiling point, °C	4347.00						-78.50
Heat of reaction, kcal	-190.41						
Reactants' density	1.60						
Gravimetric enthalpy, cal/g	-1641.15						
Volumetric enthalpy, cal/cc	-2630.69						

Table 6 (cont.)

	4 Ag	+ PbO_2	= Pb	+ 2 Ag_2O
Heat of formation		-66.12		-7.31
Molecular weight	107.87	239.21	207.21	231.76
Density	10.50	9.38	11.34	7.14
Melting point, °C	960.80	290.00	327.40	300.00
Boiling point, °C	2193.00		1750.00	
Heat of reaction, kcal	51.51			
Reactants' density	10.07			
Gravimetric enthalpy, cal/g	76.80			
Volumetric enthalpy, cal/cc	773.27			

	4 Al	+ 3 PbO_2	= 3 Pb	+ 2 Al_2O_3
Heat of formation		-66.12		-399.09
Molecular weight	26.98	239.21	207.21	101.94
Density	2.70	9.38	11.34	3.97
Melting point, °C	660.00	290.00	327.40	2015.00
Boiling point, °C	2327.00		1750.00	3500.00
Heat of reaction, kcal	-599.82			
Reactants' density	7.09			
Gravimetric enthalpy, cal/g	-726.57			
Volumetric enthalpy, cal/cc	-5149.20			

	4 As	+ 3 PbO_2	= 3 Pb	+ 2 As_2O_3
Heat of formation		-66.12		-156.15
Molecular weight	74.92	239.21	207.21	197.82
Density	5.73	9.38	11.34	4.15
Melting point, °C	817.00	290.00	327.40	313.00
Boiling point, °C	817.00		1750.00	460.00
Heat of reaction, kcal	-113.94			
Reatants' density	7.89			
Gravimetric enthalpy, cal/g	-112.00			
Volumetric enthalpy, cal/cc	-884.11			

Table 6 (cont.)

	2 Be	+	PbO_2	=	Pb	+	2 BeO
Heat of formation			-65.12				-146.00
Molecular weight	9.01		239.21		207.21		25.01
Density	1.85		9.38		11.34		3.01
Melting point, °C	1283.00		290.00		327.40		2530.00
Boiling point, °C	2970.00				1750.00		3900.00
Heat of reaction, kcal	-225.88						
Reactants' density	7.30						
Gravimetric enthalpy, cal/g	-878.10						
Volumetric enthalpy, cal/cc	-6406.21						
	2 Bi	**+**	**PbO_2**	**=**	**Pb**	**+**	**2 BiO**
Heat of formation			-66.12				-49.95
Molecular weight	208.99		239.21		207.21		224.99
Density	9.80		9.38		11.34		
Melting point, °C	271.00		290.00		327.40		
Boiling point, °C	1420.00				1750.00		
Heat of reaction, kcal	-33.78						
Reactants' density	9.64						
Gravimetric enthalpy, cal/g	-51.40						
Volumetric enthalpy, cal/cc	-495.55						
	C	**+**	**PbO_2**	**=**	**Pb**	**+**	**CO_2**
Heat of formation			-66.12				-94.05
Molecular weight	12.01		239.21		207.21		44.01
Density	2.25		9.38		11.34		1.98
Melting point, °C	25.00		290.00		327.40		-56.20
Boiling point, °C	4347.00				1750.00		-78.50
Heat of reaction, kcal	-27.93						
Reactants' density	8.14						
Gravimetric enthalpy, cal/g	-111.18						
Volumetric enthalpy, cal/cc	-905.23						

Table 6 (cont.)

	4 La	+	3 PbO_2	=	3 Pb	+	2 La_2O_3
Heat of formation			-66.12				-458.00
Molecular weight	138.92		239.21		207.21		325.84
Density	6.15		9.38		11.34		6.51
Melting point, °C	880.00		290.00		327.40		2315.00
Boiling point, °C	1800.00				1750.00		4200.00
Heat of reaction, kcal	-717.64						
Reactants' density	7.63						
Gravimetric enthalpy, cal/g	-563.60						
Volumetric enthalpy, cal/cc	-4299.78						

	4 Li	+	PbO_2	=	Pb	+	2 Li_2O
Heat of formation			-66.12				-142.40
Molecular weight	6.94		239.21		207.21		29.88
Density	.53		9.38		11.34		2.01
Melting point, °C	180.00		290.00		327.40		1700.00
Boiling point, °C	1326.00				1750.00		
Heat of reaction, kcal	-218.68						
Reactants' density	3.44						
Gravimetric enthalpy, cal/g	-819.12						
Volumetric enthalpy, cal/cc	-2821.65						

	2 Mg	+	PbO_2	=	Pb	+	2 MgO
Heat of formation			-66.12				-143.84
Molecular weight	24.32		239.21		207.21		40.32
Density	1.74		9.38		11.34		3.58
Melting point, °C	650.00		290.00		327.40		2800.00
Boiling point, °C	1120.00				1750.00		
Heat of reaction, kcal	-221.56						
Reactants' density	5.38						
Gravimetric enthalpy, cal/g	-769.71						
Volumetric enthalpy, cal/cc	-4143.65						

Table 7

MOST ENERGETIC REACTIONS OF METALS WITH OXIDES, IN TERMS OF VOLUMETRIC ENTHALPY

Reaction	Enthalpy, cal/cc
$2\ Be + RuO_2 = Ru + 2\ BeO$	-8279
$5\ Be + N_2O_5 = 2\ N^* + 5\ BeO$	-7987
$7\ Be + Re_2O_7 = 2\ Re + 7\ BeO$	-7773
$4\ Be + RuO_4 = Ru + 4\ BeO$	-7616
$2\ Be + NO_2 = N + 2\ BeO$	-7390
$4\ Be + N_2O_4 = 2\ N + 4\ BeO$	-7221
$2\ Be + SO_2 = S + 2\ BeO$	-6987
$4\ Be + 10\ SO_4 = 10\ S + 4\ BeO$	-6880
$3\ Be + N_2O_3 = 2\ N + 3\ BeO$	-6820
$U + RuO_2 = Ru + UO_2$	-6815
$5\ U + 2\ N_2O_5 = 4\ N + 5\ UO_2$	-6812
$5\ Hf + 2\ N_2O_5 = 4\ N + 5\ HfO_2$	-6732
$Hf + RuO_2 = Ru + HfO_2$	-6717
$2\ Be + Ag_2O_2 = 2\ Ag + 2\ BeO$	-6637
$10\ Al + 3\ N_2O_5 = 6\ N + 5\ Al_2O_3$	-6613
$4\ Al + 3\ RuO_2 = 3\ Ru + 2\ Al_2O_3$	-6571
$Hf + NO_2 = N + HfO_2$	-6314
$5\ Zr + 2\ N_2O_5 = 4\ N + 5\ ZrO_2$	-6266
$7\ U + 2\ Re_2O_7 = 4\ Re + 7\ UO_2$	-6246
$8\ Al + 3\ RuO_4 = 3\ Ru + 4\ Al_2O_3$	-6235
$2\ Be + SeO_2 = Se + 2\ BeO$	-6227
$2\ U + N_2O_4 = 2\ N + 2\ UO_2$	-6221
$4\ Al + 3\ NO_2 = 3\ N + 2\ Al_2O_3$	-6206
$2\ Be + MnO_2 = Mn + 2\ BeO$	-6194
$2\ Be + CO_2 = C + 2\ BeO$	-6185
$2\ Hf + N_2O_4 = 2\ N + 2\ HfO_2$	-6158
$7\ Hf + 2\ Re_2O_7 = 4\ Re + 7\ HfO_2$	-6153
$Zr + RuO_2 = Ru + ZrO_2$	-6152
$Be + NO = N + BeO$	-6147
$2\ U + RuO_4 = Ru + 2\ RuO_2$	-6435

Table 7 (cont.)

Reaction							Enthalpy, cal/cc
2 Be	+	PbO_2	=	Pb	+	2 BeO	-6406
3 Be	+	CO_2O_3	=	2 CO	+	3 BeO	-6389
U	+	NO_2	=	N	+	UO_2	-6379
2 Hf	+	RuO_4	=	Ru	+	2 HfO_2	-6359
5 Be	+	As_2O_5	=	2 As	+	5 BeO	-6345
Be	+	CuO	=	Cu	+	BeO	-6330
4 Be	+	Co_3O_4	=	3 Co	+	4 BeO	-6321
Hf	+	NO_2	=	N	+	HfO_2	-6314
5 Zr	+	2 N_2O_5	=	4 N	+	5 ZrO_2	-6266
7 U	+	2 Re_2O_7	=	4 Re	+	7 UO_2	-6246
8 Al	+	3 RuO_4	=	3 Ru	+	4 Al_2O_3	-6235
2 Be	+	SeO_2	=	Se	+	2 BeO	-6227
2 U	+	N_2O_4	=	2 N	+	2 UO_2	-6221
4 Al	+	3 NO_2	=	3 N	+	2 Al_2O_3	-6206
2 Be	+	MnO_2	=	Mn	+	2 BeO	-6194
2 Be	+	CO_2	=	C	+	2 BeO	-6185
2 Hf	+	N_2O_4	=	2 N	+	2 HfO_2	-6158
Be	+	NO	=	N	+	BeO	-6147
5 Th	+	2 N_2O_5	=	4 N	+	5 ThO_2	-6123
Be	+	N_2O	=	2 N	+	BeO	-6098
5 Np	+	2 N_2O_5	=	4 N	+	5 NpO_2	-6083
8 Al	+	3 N_2O_4	=	6 N	+	4 Al_2O_3	-6050
Th	+	RuO_2	=	Ru	+	ThO_2	-6003
14 Al	+	3 Re_2O_7	=	6 Re	+	7 Al_2O_3	-5995
10 Ti	+	3 N_2O_5	=	6 N	+	5 Ti_2O_3	-5941
3 U	+	2 N_2O_3	=	4 N	+	3 UO_2	-5933
Np	+	RuO_2	=	Ru	+	NpO_2	-5926
Zr	+	NO_2	=	N	+	ZrO_2	-5902
4 B	+	3 RuO_2	=	3 Ru	+	2 B_2O_3	-5889
2 Zr	+	RuO_4	=	Ru	+	2 ZrO_2	-5888
Be	+	NiO	=	Ni	+	BeO	-5880
3 Hf	+	2 N_2O_3	=	4 N	+	3 HfO_2	-5879

Table 7 (cont.)

Reaction							Enthalpy, cal/cc
2 Be	+	TeO_2	=	Te	+	2 BeO	-5831
Th	+	NO_2	=	N	+	ThO_2	-5818
3 Be	+	CrO_3	=	Cr	+	3 BeO	-5799
2 Th	+	RuO_4	=	Ru	+	2 ThO_2	-5795
2 Al	+	N_2O_3	=	2 N	+	Al_2O_3	-5780
2 U	+	10 SO_4	=	10 S	+	2 UO_2	-5779
4 Ti	+	3 RuO_2	=	3 Ru	+	2 Ti_2O_3	-5757
10 Ho	+	3 N_2O_5	=	6 N	+	5 Ho_2O_3	-5751
2 Zr	+	N_2O_4	=	2 N	+	2 ZrO_2	-5750
U	+	SO_2	=	S	+	UO_2	-5749
Np	+	NO_2	=	N	+	NpO_2	-5732
U	+	Ag_2O_2	=	2 Ag	+	UO_2	-5728
2 Hf	+	10 SO_4	=	10 S	+	2 HfO_2	-5716
2 Np	+	RuO_4	=	Ru	+	2 NpO_2	-5692
2 Th	+	N_2O_4	=	2 N	+	2 ThO_2	-5685
Hf	+	SO_2	=	S	+	HfO_2	-5679
Hf	+	Ag_2O_2	=	2 Ag	+	HfO_2	-5676
4 B	+	3 NO_2	=	3 N	+	2 B_2O_3	-5668
2 Be	+	WO_2	=	W	+	2 BeO	-5646
4 Ti	+	3 NO_2	=	3 N	+	2 Ti_2O_3	-5610
8 B	+	3 RuO_4	=	3 Ru	+	4 B_2O_3	-5607
2 Ta	+	N_2O_5	=	2 N	+	Ta_2O_5	-5593
8 Al	+	3 OsO_4	=	3 Os	+	4 Al_2O_3	-5592
4 Ho	+	3 RuO_2	=	3 Ru	+	2 Ho_2O_3	-5582
2 Np	+	N_2O_4	=	2 N	+	2 NpO_2	-5576
4 Al	+	3 Ag_2O_2	=	6 Ag	+	2 Al_2O_3	-5572
7 Zr	+	2 Re_2O_7	=	4 Re	+	7 ZrO_2	-5562
8 Ti	+	3 RuO_4	=	3 Ru	+	4 Ti_2O_3	-5553
10 Tb	+	3 N_2O_5	=	6 N	+	5 Tb_2O_3	-5549
4 Al	+	3 SO_2	=	3 S	+	2 Al_2O_3	-5542
3 Be	+	MoO_3	=	Mo	+	3 BeO	-5528

Table 7 (cont.)

Reaction									Enthalpy, cal/cc
3 Zr	+	2 N_2O_3	=	4 N	+	3 ZrO_2			-5510
7 Th	+	2 Re_2O_7	=	4 Re	+	7 ThO_2			-5505
4 Ho	+	3 NO_2	=	3 N	+	2 Ho_2O_3			-5500
2 Be	+	MoO_2	=	Mo	+	2 BeO			-5487
8 B	+	3 N_2O_4	=	6 N	+	4 B_2O_3			-5481
3 Th	+	2 N_2O_3	=	4 N	+	3 ThO_2			-5477
8 Ti	+	3 N_2O_4	=	6 N	+	4 Ti_2O_3			-5457
10 Sm	+	3 N_2O_5	=	6 N	+	5 Sm_2O_3			-5449
U	+	2 NO	=	2 N	+	UO_2			-5445
8 Ho	+	3 RuO_4	=	3 Ru	+	4 Ho_2O_3			-5443
10 Gd	+	3 N_2O_5	=	6 N	+	5 Gd_2O_3			-5412
Hf	+	2 NO	=	2 N	+	HfO_2			-5406
U	+	2 N_2O	=	4 N	+	UO_2			-5395
8 Ho	+	3 N_2O_4	=	6 N	+	4 Ho_2O_3			-5377
10 Sc	+	3 N_2O_5	=	6 N	+	5 Sc_2O_3			-5368
10 Nd	+	3 N_2O_5	=	6 N	+	5 Nd_2O_3			-5363
Hf	+	2 N_2O	=	4 N	+	HfO_2			-5357
3 Be	+	Fe_2O_3	=	2 Fe	+	3 BeO			-5355
4 Tb	+	3 RuO_2	=	3 Ru	+	2 Tb_2O_3			-5349
3 Np	+	2 N_2O_3	=	4 N	+	3 NpO_2			-5348
10 La	+	3 N_2O_5	=	6 N	+	5 La_2O_3			-5339
U	+	PbO_2	=	Pb	+	UO_2			-5330
2 Al	+	3 NO	=	3 N	+	Al_2O_3			-5323
4 Tb	+	3 NO_2	=	3 N	+	2 Tb_2O_3			-5316
7 Np	+	2 Re_2O_7	=	4 Re	+	7 NpO_2			-5304
5 Si	+	2 N_2O_5	=	4 N	+	5 SiO_2			-5297
Zr	+	Ag_2O_2	=	2 Ag	+	ZrO_2			-5297
10 Pr	+	3 N_2O_5	=	6 N	+	5 Pr_2O_3			-5293
Th	+	Ag_2O_2	=	2 Ag	+	ThO_2			-5289
4 Ta	+	5 RuO_2	=	5 Ru	+	2 Ta_2O_5			-5284
10 Ce	+	3 N_2O_5	=	6 N	+	5 Ce_2O_3			-5276

Table 7 (cont.)

Reaction	Enthalpy, cal/cc
$Hf + PbO_2 = Pb + HfO_2$	-5274
$2\ Al + 3\ N_2O = 6\ N + Al_2O_3$	-5273
$2\ Zr + 10\ SO_4 = 10\ S + 2\ ZrO_2$	-5266
$2\ Th + 10\ SO_4 = 10\ S + 2\ ThO_2$	-5261
$4\ Ta + 5\ NO_2 = 5\ N + 2\ Ta_2O_5$	-5256
$2\ Ti + N_2O_3 = 2\ N + Ti_2O_3$	-5242
$8\ Tb + 3\ RuO_4 = 3\ Ru + 4\ Tb_2O_3$	-5238
$4\ Sm + 3\ RuO_2 = 3\ Ru + 2\ Sm_2O_3$	-5236
$U + 2\ CuO = 2\ Cu + UO_2$	-5236
$U + SeO_2 = Se + UO_2$	-5232
$5\ Mg + N_2O_5 = 2\ N + 5\ MgO$	-5227
$4\ Sm + 3\ NO_2 = 3\ N + 2\ Sm_2O_3$	-5226
$2\ B + N_2O_3 = 2\ N + B_2O_3$	-5221
$2\ Ho + N_2O_3 = 2\ N + Ho_2O_3$	-5206
$4\ Gd + 3\ RuO_2 = 3\ Ru + 2\ Gd_2O_3$	-5194
$4\ Gd + 3\ NO_2 = 3\ N + 2\ Gd_2O_3$	-5193
$8\ Tb + 3\ N_2O_4 = 6\ N + 4\ Tb_2O_3$	-5193
$Th + SO_2 = S + ThO_2$	-5188
$3\ U + 2\ Co_2O_3 = 4\ Co + 3\ UO_2$	-5183
$5\ U + 2\ As_2O_5 = 4\ As + 5\ UO_2$	-5183
$Hf + SeO_2 = Se + HfO_2$	-5181
$Zr + SO_2 = S + ZrO_2$	-5180
$Hf + 2\ CuO = 2\ Cu + HfO_2$	-5180
$2\ Nb + N_2O_5 = 2\ N + Nb_2O_5$	-5178
$4\ Nd + 3\ NO_2 = 3\ N + 2\ Nd_2O_3$	-5154
$4\ Al + 3\ PbO_2 = 3\ Pb + 2\ Al_2O_3$	-5149
$4\ Nd + 3\ RuO_2 = 3\ Ru + 2\ Nd_2O_3$	-5145
$4\ Sc + 3\ NO_2 = 3\ N + 2\ Sc_2O_3$	-5144
$8\ Sm + 3\ RuO_4 = 3\ Ru + 4\ Sm_2O_3$	-5140
$4\ La + 3\ NO_2 = 3\ N + 2\ La_2O_3$	-5140
$14\ Ti + 3\ Re_2O_7 = 6\ Re + 7\ Ti_2O_3$	-5137

Table 7 (cont.)

Reaction							Enthalpy, cal/cc
4 Sc	+	3 RuO_2	=	3 Ru	+	2 Sc_2O_3	-5131
8 Ta	+	5 RuO_4	=	5 Ru	+	4 Ta_2O_5	-5131
4 La	+	3 RuO_2	=	3 Ru	+	2 La_2O_3	-5128
Np	+	Ag_2O_2	=	2 Ag	+	NpO_2	-5125
5 Hf	+	2 As_2O_5	=	4 As	+	5 HfO_2	-5125
3 Hf	+	2 Co_2O_3	=	4 Co	+	3 HfO_2	-5124
2 Be	+	GeO_2	=	Ge	+	2 BeO	-5118
Th	+	2 NO	=	2 N	+	ThO_2	-5117
14 Ho	+	3 Re_2O_7	=	8 Re	+	7 Ho_2O_3	-5113
Be	+	HgO	=	Hg	+	BeO	-5112
Zr	+	2 NO	=	2 N	+	ZrO_2	-5105
8 Sm	+	3 N_2O_4	=	6 N	+	4 Sm_2O_3	-5105
8 Gd	+	3 RuO_4	=	3 Ru	+	4 Gd_2O_3	-5104
U	+	10 SO_2	=	10 S	+	UO_2	-5095
4 Pr	+	3 NO_2	=	3 N	+	2 Pr_2O_3	-5093
8 Ta	+	5 N_2O_4	=	10 N	+	4 Ta_2O_5	-5082
4 Ce	+	3 NO_2	=	3 N	+	2 Ce_2O_3	-5074
8 Gd	+	3 N_2O_4	=	6 N	+	4 Gd_2O_3	-5073
Th	+	2 N_2O	=	4 N	+	ThO_2	-5072
4 Pr	+	3 RuO_2	=	3 Ru	+	2 Pr_2O_3	-5070
2 U	+	Co_3O_4	=	3 Co	+	2 UO_2	-5066
8 Nd	+	3 RuO_4	=	3 Ru	+	4 Nd_2O_3	-5063
14 B	+	3 Re_2O_7	=	6 Re	+	7 B_2O_3	-5063
4 Al	+	3 SeO_2	=	3 Se	+	2 Al_2O_3	-5063
2 Np	+	10 SO_4	=	10 S	+	2 NpO_2	-5061
Zr	+	2 N_2O	=	4 N	+	ZrO_2	-5055
8 La	+	3 RuO_4	=	3 Ru	+	4 La_2O_3	-5051
2 Al	+	3 CuO	=	3 Cu	+	Al_2O_3	-5051
Hf	+	10 SO_2	=	10 S	+	HfO_2	-5046
3 Be	+	WO_3	=	W	+	3 BeO	-5045
4 Ce	+	3 RuO_2	=	3 Ru	+	2 Ce_2O_3	-5045

Table 7 (cont.)

Reaction									Enthalpy, cal/cc
8	Sc	+	3 RuO_4	=	3	Ru	+	4 Sc_2O_3	-5044
2	Tb	+	N_2O_3	=	2	N	+	Tb_2O_3	-5036
8	Nd	+	3 N_2O_4	=	6	N	+	4 Nd_2O_3	-5036
2	Mg	+	NO_2	=		N	+	2 MgO	-5029
	U	+	CO_2	=		C	+	UO_2	-5028
8	La	+	3 N_2O_4	=	6	N	+	4 La_2O_3	-5026
4	Ho	+	3 Ag_2O_2	=	6	Ag	+	2 Ho_2O_3	-5024
10	V	+	3 N_2O_5	=	6	N	+	5 V_2O_3	-5020
8	Sc	+	3 N_2O_4	=	6	N	+	4 Sc_2O_3	-5018
4	Ti	+	3 Ag_2O_2	=	6	Ag	+	2 Ti_2O_3	-5018
	Si	+	NO_2	=		N	+	SiO_2	-5015
2	Hf	+	Co_3O_4	=	3	Co	+	2 HfO_2	-5006
8	Pr	+	3 RuO_4	=	3	Ru	+	4 Pr_2O_3	-4997
2	Mg	+	RuO_2	=		Ru	+	2 MgO	-4989
10	Al	+	3 As_2O_5	=	6	As	+	5 Al_2O_3	-4988
2	Al	+	Co_2O_3	=	2	Co	+	Al_2O_3	-4983
8	Pr	+	3 N_2O_4	=	6	N	+	4 Pr_2O_3	-4978
8	Ce	+	3 RuO_4	=	3	Ru	+	4 Ce_2O_3	-4974
	Hf	+	CO_2	=		C	+	HfO_2	-4973
	Np	+	2 NO	=	2	N	+	NpO_2	-4964
8	Ho	+	3 OsO_4	=	3	Os	+	4 Ho_2O_3	-4960
8	Ce	+	3 N_2O_4	=	6	N	+	4 Ce_2O_3	-4956
2	Sm	+	N_2O_3	=	2	N	+	Sm_2O_3	-4955
	Np	+	SO_2	=		S	+	NpO_2	-4951
4	B	+	3 Ag_2O_2	=	6	Ag	+	2 B_2O_3	-4951
	Si	+	RuO_2	=		Ru	+	SiO_2	-4950
3	U	+	2 SO_3	=	2	S	+	3 UO_2	-4949

*N refers to molecular nitrogen and is thus 1/2 N_2.

Table 8

MOST ENERGETIC REACTIONS OF METALS WITH OXIDES, IN TERMS OF GRAVIMETRIC ENTHALPY

Reaction	Enthalpy, cal/g
$3\ Be + NO_3 = N^* + 3\ BeO$	-5064
$5\ Be + N_2O_5 = 2\ N + 5\ BeO$	-4703
$2\ Be + NO_2 = N + 2\ BeO$	-4686
$4\ Be + N_2O_4 = 2\ N + 4\ BeO$	-4578
$3\ Be + N_2O_3 = 2\ N + 3\ BeO$	-4444
$1\ Be + NO = N + BeO$	-4294
$6\ Li + NO_3 = N + 3\ Li_2O$	-4246
$4\ Li + NO_2 = N + 2\ Li_2O$	-3970
$10\ Li + N_2O_5 = 2\ N + 5\ Li_2O$	-3956
$8\ Li + N_2O_4 = 2\ N + 4\ Li_2O$	-3876
$6\ Li + N_2O_3 = 2\ N + 3\ Li_2O$	-3800
$2\ B + NO_3 = N + B_2O_3$	-3765
$2\ Li + NO = N + Li_2O$	-3736
$2\ Al + NO_3 = N + Al_2O_3$	-3553
$4\ B + 3\ NO_2 = 3\ N + 2\ B_2O_3$	-3465
$10\ B + 3\ N_2O_5 = 3\ N + 5\ B_2O_3$	-3423
$8\ B + 3\ N_2O_4 = 6\ N + 4\ B_2O_3$	-3350
$4\ Al + 3\ NO_2 = 3\ N + 2\ Al_2O_3$	-3343
$10\ Al + 3\ N_2O_5 = 6\ N + 5\ Al_2O_3$	-3309
$2\ B + N_2O_3 = 2\ N + B_2O_3$	-3297
$3\ Mg + NO_3 = N + 3\ MgO$	-3293
$2\ B + 3\ NO = 3\ N + B_2O_3$	-3284
$8\ Al + 3\ N_2O_4 = 6\ N + 4\ Al_2O_3$	-3259
$Be + CO = C + BeO$	-3230
$2\ Al + N_2O_3 = 2\ N + Al_2O_3$	-3224
$2\ Al + 3\ NO = 3\ N + Al_2O_3$	-3221
$2\ Be + CO_2 = C + 2\ BeO$	-3190
$2\ Be + NaO_2 = Na + 2\ BeO$	-3151
$2\ Mg + NO_2 = N + 2\ MgO$	-3124

Table 8 (cont.)

Reaction	Enthalpy, cal/g
$Be + N_2O = 2\,N + BeO$	-3120
$3\,Si + 2\,NO_3 = 2\,N + 3\,SiO_2$	-3083
$4\,Mg + N_2O_4 = 2\,N + 4\,MgO$	-3051
$Mg + NO = N + MgO$	-3045
$3\,Mg + N_2O_3 = 2\,N + 3\,MgO$	-3030
$Si + NO_2 = N + SiO_2$	-2881
$5\,Si + 2\,N_2O_5 = N + 5\,SiO_2$	-2824
$Si + 2\,NO = 2\,N + SiO_2$	-2821
$2\,Li + N_2O = 2\,N + Li_2O$	-2796
$2\,Sc + NO_3 = N + Sc_2O_3$	-2790
$2\,Si + N_2O_4 = 2\,N + 2\,SiO_2$	-2787
$3\,Si + 2\,N_2O_3 = 2\,N + 3\,SiO_2$	-2776
$2\,Li + CO = C + Li_2O$	-2769
$4\,Li + NaO_2 = Na + 2\,Li_2O$	-2693
$2\,Be + SO_2 = 2\,S + 2\,BeO$	-2692
$4\,Sc + 3\,NO_2 = 3\,N + 2\,Sc_2O_3$	-2662
$4\,Li + CO_2 = C + 2\,Li_2O$	-2657
$6\,Li + SO_3 = S + 3\,Li_2O$	-2650
$2\,Sc + 3\,NO = 3\,N + Sc_2O_3$	-2644
$4\,Be + RuO_4 = Ru + 4\,BeO$	-2636
$10\,Sc + 3\,N_2O_5 = 6\,N + 5\,Sc_2O_3$	-2617
$5\,Be + MoO_5 = Mo + 5\,BeO$	-2601
$2\,Sc + N_2O_3 = 2\,N + Sc_2O_3$	-2597
$8\,Sc + 3\,N_2O_4 = 6\,N + 4\,Sc_2O_3$	-2597
$3\,Ca + NO_3 = N + 3\,CaO$	-2571
$4\,Be + K_2O_4 = 2\,K + 4\,BeO$	-2524
$Ca + NO = N + CaO$	-2475
$2\,Ca + NO_2 = N + 2\,CaO$	-2471
$2\,Al + 3\,N_2O = 3\,N + Al_2O_3$	-2459
$Be + SO = S + BeO$	-2452
$5\,Ca + N_2O_5 = 2\,N + 5\,CaO$	-2430

Table 8 (cont.)

Reaction									Enthalpy, cal/g
3 Ca	+	N_2O_3	=	2 N	+	3 CaO			-2423
4 Ca	+	N_2O_4	=	2 N	+	4 CaO			-2417
Mg	+	N_2O	=	2 N	+	MgO			-2389
3 Be	+	CrO_3	=	Cr	+	3 BeO			-2358
2 B	+	3 N_2O	=	6 N	+	1 B_2O_3			-2345
8 Li	+	RuO_4	=	Ru	+	4 Li_2O			-2339
Be	+	SiO	=	Si	+	BeO			-2331
4 Li	+	SO_2	=	S	+	2 Li_2O			-2328
2 Ti	+	3 NO	=	3 N	+	Ti_2O_3			-2323
2 Al	+	3 CO	=	3 C	+	Al_2O_3			-2318
4 Ti	+	3 NO_2	=	6 N	+	2 Ti_2O_3			-2300
4 Be	+	Nb_2O_4	=	2 Nb	+	4 BeO			-2284
2 P	+	NO_3	=	N	+	P_2O_3			-2282
10 Li	+	MoO_5	=	Mo	+	5 Li_2O			-2269
2 Ti	+	N_2O_3	=	2 N	+	Ti_2O_3			-2252
10 Ti	+	3 N_2O_5	=	6 N	+	5 Ti_2O_3			-2247
4 Al	+	3 NaO_2	=	3 Na	+	2 Al_2O_3			-2244
Mg	+	CO	=	C	+	MgO			-2244
8 Ti	+	3 N_2O_4	=	6 N	+	4 Ti_2O_3			-2237
8 Li	+	K_2O_4	=	2 K	+	4 Li_2O			-2203
2 P	+	3 NO	=	3 N	+	P_2O_3			-2202
2 Li	+	SO	=	S	+	Li_2O			-2201
2 Al	+	SO_3	=	S	+	Al_2O_3			-2197
2 Be	+	Li_2O_2	=	2 Li	+	2 BeO			-2195
2 Mg	+	NaO_2	=	Na	+	2 MgO			-2178
4 P	+	3 NO_2	=	3 N	+	2 P_2O_3			-2154
4 Al	+	3 CO_2	=	3 C	+	2 Al_2O_3			-2150
3 Mg	+	SO_3	=	S	+	3 MgO			-2136
2 Sc	+	3 N_2O	=	6 N	+	Sc_2O_3			-2114
2 B	+	3 CO	=	3 C	+	B_2O_3			-2108
Si	+	2 N_2O	=	4 N	+	SiO_2			-2104

Table 8 (cont.)

Reaction							Enthalpy, cal/g
2 P	+	N_2O_3	=	2 N	+	P_2O_3	-2101
4 Be	+	MoO_4	=	Mo	+	4 BeO	-2094
2 Mg	+	CO_2	=	C	+	2 MgO	-2089
10 P	+	3 N_2O_3	=	6 N	+	5 P_2O_3	-2082
8 P	+	3 N_2O_4	=	6 N	+	4 P_2O_3	-2075
2 Li	+	SiO	=	Si	+	Li_2O	-2073
3 Be	+	K_2O_3	=	2 K	+	3 BeO	-2042
6 Li	+	CrO_3	=	Cr	+	3 Li_2O	-2038
Ca	+	N_2O	=	2 N	+	CaO	-2037
7 Be	+	Tc_2O_7	=	2 Tc	+	7 BeO	-2026
8 Al	+	3 RuO_4	=	3 Ru	+	4 Al_2O_3	-2020
3 Zr	+	2 NO_3	=	2 N	+	3 ZrO_2	-2013
4 B	+	3 NaO_2	=	3 Na	+	2 B_2O_3	-2008
Zr	+	2 NO	=	2 N	+	ZrO_2	-1992
4 Mg	+	RuO_4	=	Ru	+	4 MgO	-1990
4 Al	+	3 SO_2	=	3 S	+	2 Al_2O_3	-1950
2 B	+	SO_3	=	S	+	B_2O_3	-1940
Zr	+	NO_2	=	N	+	ZrO_2	-1940
3 C	+	2 NO_3	=	2 N	+	3 CO_2	-1925
2 Be	+	MgO_2	=	Mg	+	2 BeO	-1924
2 Al	+	3 SO	=	3 S	+	Al_2O_3	-1923
2 Mg	+	SO_2	=	S	+	2 MgO	-1922
10 Al	+	3 MoO_5	=	3 Mo	+	5 Al_2O_3	-1918
3 Zr	+	2 N_2O_3	=	4 N	+	3 ZrO_2	-1913
2 Sc	+	3 CO	=	3 C	+	Sc_2O_3	-1907
C	+	2 NO	=	2 N	+	CO_2	-1905
Mg	+	SO	=	S	+	MgO	-1904
5 Mg	+	MoO_5	=	Mo	+	5 MgO	-1895
2 Zr	+	N_2O_4	=	2 N	+	2 ZrO_2	-1890
5 Zr	+	2 N_2O_5	=	4 N	+	5 ZrO_2	-1890
3 Ti	+	NO_3	=	N	+	3 TiO	-1870
2 Ti	+	3 N_2O	=	6 N	+	Ti_2O_3	-1867

Table 8 (cont.)

Reaction	Enthalpy, cal/g
$5\ Be + As_2O_5 = 2\ As + 5\ BeO$	-1860
$8\ Al + 3\ K_2O_4 = 6\ K + 4\ Al_2O_3$	-1859
$2\ V + 3\ NO = 3\ N + V_2O_3$	-1848
$2\ V + NO_3 = N + V_2O_3$	-1848
$4\ Sc + 3\ NaO_2 = 3\ Na + 2\ Sc_2O_3$	-1845
$Ca + CO = C + CaO$	-1843
$4\ Mg + K_2O_4 = 2\ K + 4\ MgO$	-1842
$8\ Li + MoO_4 = Mo + 4\ Li_2O$	-1838
$4\ B + 3\ CO_2 = 3\ C + 2\ B_2O_3$	-1835
$2\ Be + SeO_2 = Se + 2\ BeO$	-1826
$Si + 2\ CO = 2\ C + SiO_2$	-1814
$8\ B + 3\ RuO_4 = 3\ Ru + 4\ B_2O_3$	-1802
$2\ Sc + SO_3 = S + Sc_2O_3$	-1802
$6\ Li + K_2O_3 = 2\ K + 3\ Li_2O$	-1800
$14\ Li + Tc_2O_7 = Tc + 7\ Li_2O$	-1794
$2\ Ca + NaO_2 = Na + 2\ CaO$	-1789
$2\ Al + 3\ SiO = 3\ Si + Al_2O_3$	-1785
$2\ Be + Na_2O_2 = 2\ Na + 2\ BeO$	-1785
$8\ Be + Re_2O_8 = 2\ Re + 8\ BeO$	-1780
$Mg + SiO = Si + MgO$	-1778
$3\ Be + TcO_3 = Tc + 3\ BeO$	-1775
$4\ V + 3\ NO_2 = 3\ N + 2\ V_2O_3$	-1767
$C + NO_2 = N + CO_2$	-1760
$3\ Ca + SO_3 = S + 3\ CaO$	-1752
$2\ V + N_2O_3 = 2\ N + V_2O_3$	-1742
$8\ Sc + 3\ RuO_4 = 3\ Ru + 4\ Sc_2O_3$	-1736
$4\ Sc + 3\ CO_2 = 3\ C + 2\ Sc_2O_3$	-1731
$8\ Li + Nb_2O_4 = 2\ Nb + 4\ Li_2O$	-1725
$2\ Cr + 3\ NO = 3\ N + Cr_2O_3$	-1723
$2\ B + 3\ SO = 3\ S + B_2O_3$	-1712
$3\ C + 2\ N_2O_3 = 4\ N + 3\ CO_2$	-1712
$8\ V + 3\ N_2O_4 = 6\ N + 4\ V_2O_3$	-1707
$4\ Ca + RuO_4 = Ru + 4\ CaO$	-1704

Table 8 (cont.)

Reaction	Enthalpy, cal/g
$10\,V + 3\,N_2O_5 = 6\,N + 5\,V_2O_3$	-1703
$2\,Cr + NO_3 = N + Cr_2O_3$	-1702
$2\,Nb + 5\,NO = 5\,N + Nb_2O_5$	-1700
$Be + InO = In + BeO$	-1695
$3\,Mg + CrO_3 = Cr + 3\,MgO$	-1694
$2\,P + 3\,N_2O = 6\,N + P_2O_3$	-1693
$2\,Al + CrO_3 = Cr + Al_2O_3$	-1693
$4\,Be + OsO_4 = Os + 4\,BeO$	-1690
$4\,Be + Rb_2O_4 = 2\,Rb + 4\,BeO$	-1689
$2\,Ca + CO_2 = C + 2\,CaO$	-1689
$2\,Sc + 3\,SO = 3\,S + Sc_2O_3$	-1678
$6\,Nb + 5\,NO_3 = 5\,N + 3\,Nb_2O_5$	-1676
$3\,Si + 2\,SO_3 = 2\,S + 3\,SiO_2$	-1665
$4\,B + 3\,SO_2 = 3\,S + 2\,B_2O_3$	-1661
$Zr + 2\,N_2O = 4\,N + ZrO_2$	-1657
$Ca + SO = S + CaO$	-1655
$10\,Li + As_2O_5 = 2\,As + 5\,Li_2O$	-1649
$4\,Li + SeO_2 = Se + 2\,Li_2O$	-1646
$10\,B + 3\,MoO_5 = 3\,Mo + 5\,B_2O_3$	-1642
$2\,C + N_2O_4 = 2\,N + 2\,CO_2$	-1641
$4\,Sc + 3\,SO_2 = 3\,S + 2\,Sc_2O_3$	-1637
$5\,C + 2\,N_2O_5 = 4\,N + 5\,CO_2$	-1630
$4\,Cr + 3\,NO_2 = 3\,N + 2\,Cr_2O_3$	-1628
$10\,Sc + 3\,MoO_5 = 3\,Mo + 5\,Sc_2O_3$	-1626
$16\,Li + Re_2O_8 = 2\,Re + 8\,Li_2O$	-1620
$2\,Si + RuO_4 = Ru + 2\,SiO_2$	-1617
$4\,Li + MgO_2 = Mg + 2\,Li_2O$	-1616
$2\,Ca + SO_2 = S + 2\,CaO$	-1614
$2\,Li + InO = In + Li_2O$	-1613
$2\,Cr + N_2O_3 = 2\,N + Cr_2O_3$	-1609
$4\,Nb + 5\,NO_2 = 5\,N + 2\,Nb_2O_5$	-1606
$5\,Ca + MoO_5 = Mo + 5\,CaO$	-1605
$2\,Ti + 3\,CO = 3\,C + Ti_2O_3$	-1600
$2\,Be + MnO_2 = Mn + 2\,BeO$	-1595
$6\,Nb + 5\,N_2O_3 = 10\,N + 3\,Nb_2O_5$	-1588

*Refers to molecular nitrogen and is thus 1/2 N_2.

The oxides of nitrogen are excellent oxidizers because they uniquely combine the characteristics of a slightly positive heat of formation, a small gram-atomic volume, and small values of z and y in their stoichiometric equations. In addition to the unusually large thermal outputs, their reactions are unique in other respects. For instance, with many metals either gaseous nitrogen or a metal nitride is produced:

$$Be + 1/4\ N_2O_4 \longrightarrow 1/4\ N_2 + BeO$$

$$7/4\ Be + 1/4\ N_2O_4 \longrightarrow 1/4\ Be_3N_2 + BeO$$

Only the reactions producing gaseous nitrogen were considered here.

The periodicity of the enthalpies is illustrated in Figures 5, 6, and 7. The periodic behavior demonstrated by the oxides is somewhat different from that of the fluorides. Energy peaks (actually minima in the curves) occur at every ninth atomic number, forming the series beryllium, aluminum, titanium, gallium, zirconium, indium, and hafnium. Except for beryllium, these elements comprise Groups IIIA and IVB. In this analysis the elements from lanthanum to lutetium are considered as one unit. The rare earth elements, lanthanum to holmium and probably thorium to element 103, also form a broad energy peak within the peaks separated by nine units. The elements at the energy peaks are characterized by the electronic configuration of their valence orbitals. The electronic configuration in the oxides is the rare gas s^2 or s^2p^6 or the pseudo rare gas $s^2p^6d^{10}$. Other characterizing features of the energy peaks are the high heats of formation of their oxides relative to the oxides of their immediate neighbors, their low gram-atomic volumes, and their low values of z and y due to the stoichiometry of their oxidation states.

The high volumetric energy outputs exhibited by the reactions with beryllium are due to the extremely low atomic volume of the metal. It also exhibits a high gravimetric energy output because its atomic weight is low. Because of these factors, the heat of formation of the oxide per unit volume and per unit weight is comparatively high. The heat of formation of magnesium oxide is about the same as that of beryllium oxide, but the atomic volume and the atomic weight of the metal are greater. Magnesium reactions are therefore not as energetic as beryllium reactions.

A similar situation exists between boron and aluminum. The smaller atomic volume and atomic weight of boron tend to increase the volumetric and gravimetric energies of its reactions. But aluminum reactions are much more energetic because aluminum oxide has a muchhigher heat of formation than boric oxide. These factors are discussed more thoroughly under nitrate reactions.

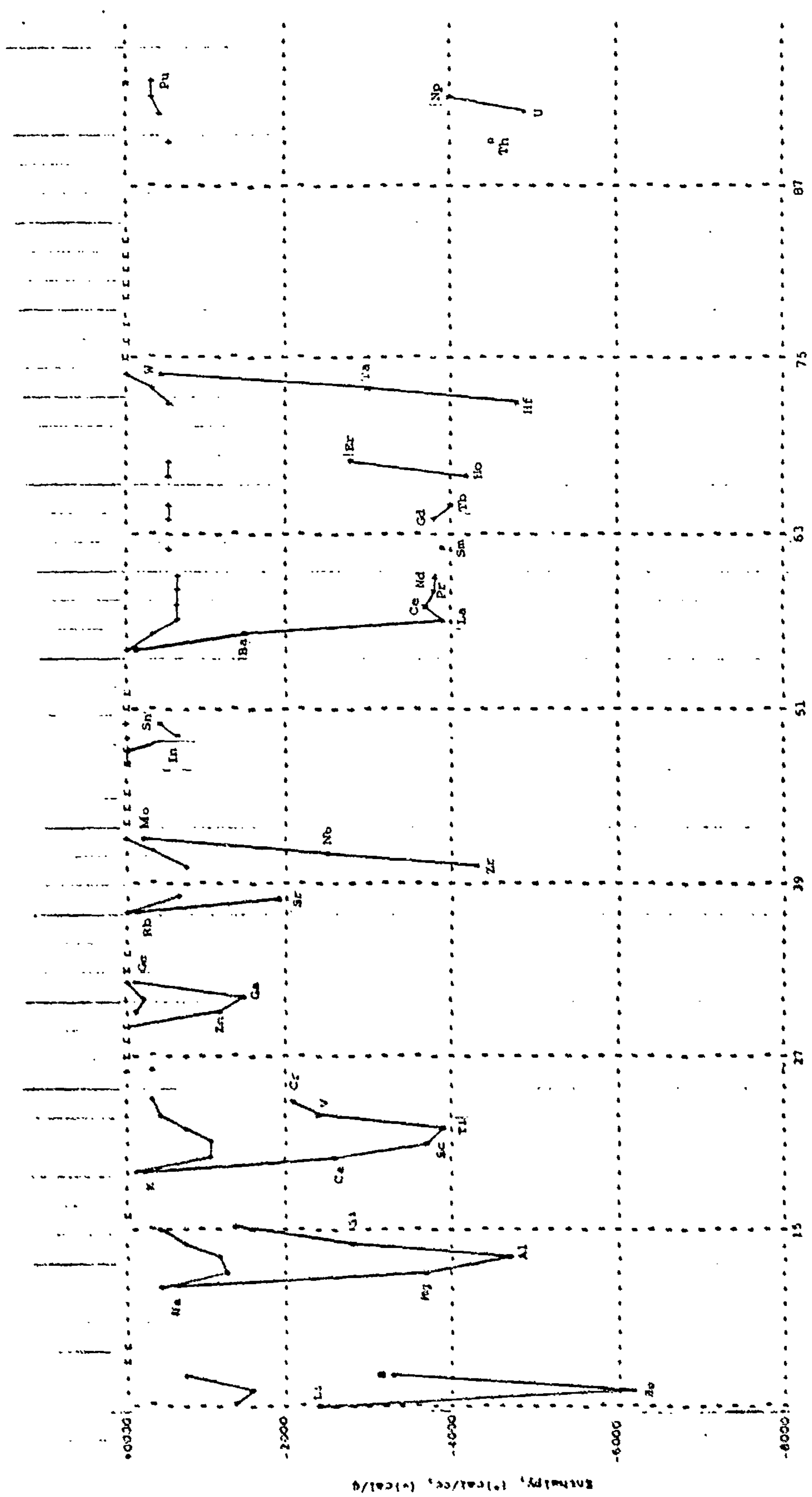


Figure 5

GRAVIMETRIC AND VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH MnO_2

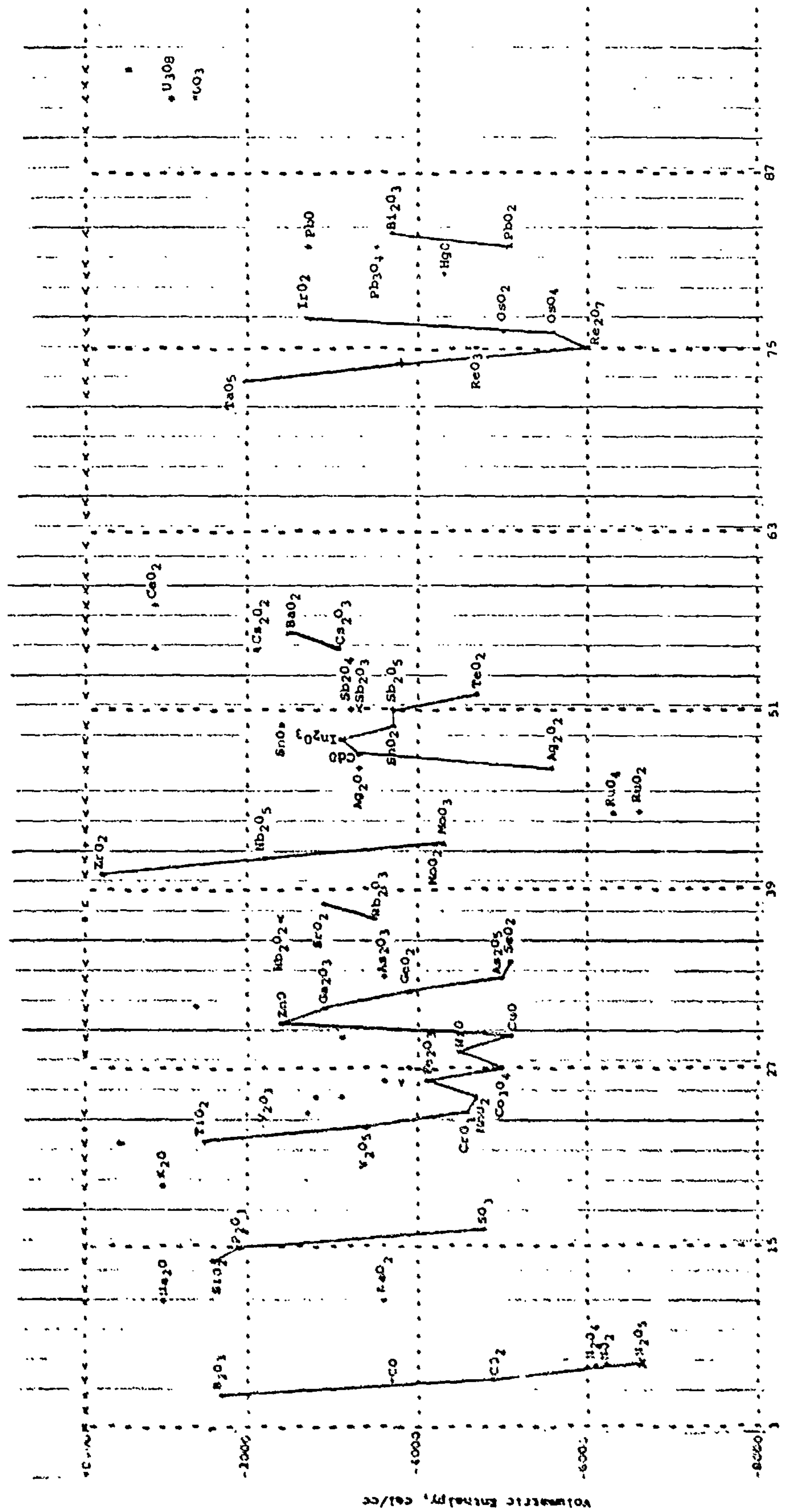


Figure 6

VOLUMETRIC ENTHALPIES OF REACTIONS OF OXIDES WITH Al

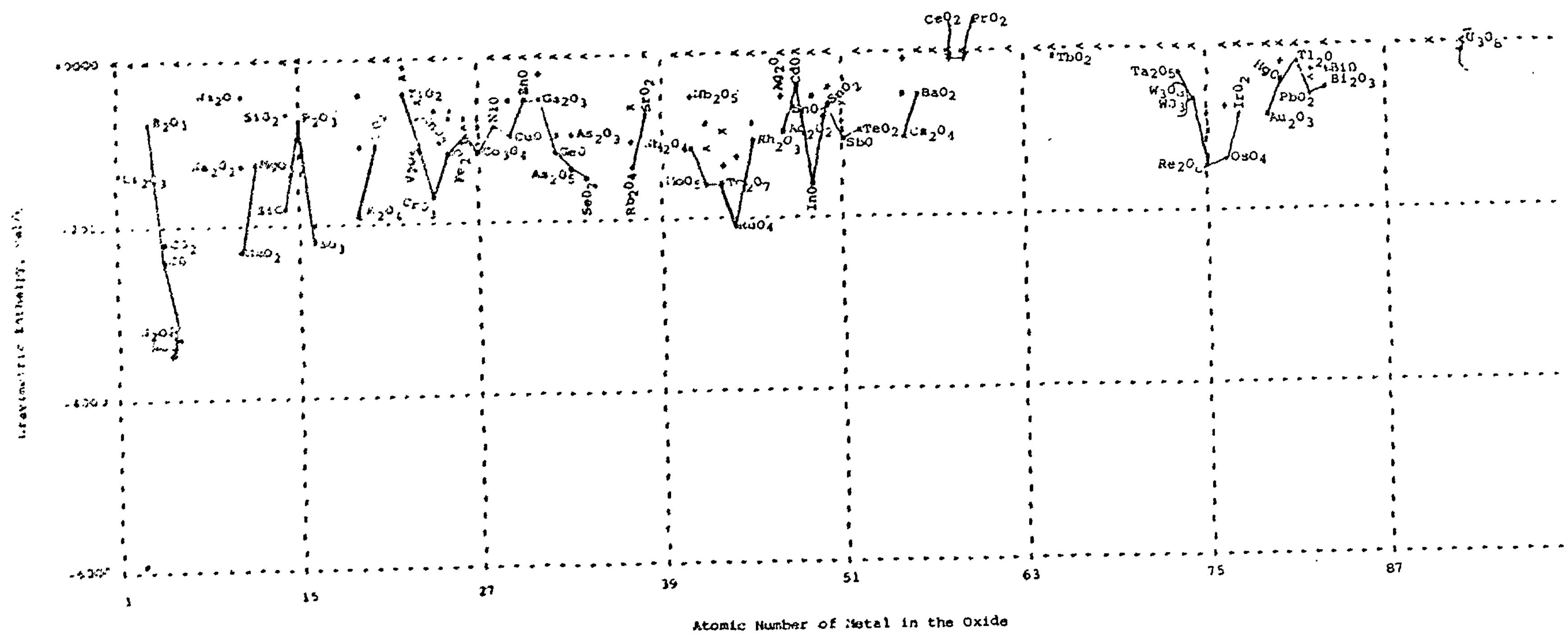


Figure 7

GRAVIMETRIC ENTHALPIES OF REACTIONS OF OXIDES WITH Al

Titanium, zirconium, and hafnium occupy peak positions because their gram-atomic volumes are relatively low and the heats of formation of their oxides are relatively high. Although gallium and indium have very low energy outputs, they are higher than their immediate neighbors because of their lower gram-atomic volumes and because of the higher heats of formation of their oxides relative to those of their neighbors. The extremely low gram-atomic volume of beryllium placed it in a peak position, in spite of the relatively low heat of formation of its oxide.

The peak positions of the rare earths lanthanum to holmium are due to the reverse phenomenon. Their relatively large gram-atomic volumes are compensated by the extremely high heats of formation of their oxides. Although data are not available, it seems that the energy outputs of all the members of the rare earth series should be comparable and therefore they will establish a horizontal position in the curve between lanthanum and lutetium. The volumetric energy for erbium is based on a questionable value for the density of the metal--4.77 g/cc.[5] The anomalous position it occupies in the volumetric curve indicates that this density is probably in error. The interposition of the rare earth elements between zirconium and hafnium plus the lanthanide contraction cause hafnium to have a gram-atomic value comparable to that of zirconium even though its atomic weight is much greater.

The trend of the enthalpies within the various groups of the periodic table is similar to that of the fluorides (Figure 1B). The energy decreases from lithium to cesium. Group IIA energies also decrease from beryllium to barium. The Group II values are higher than the Group I values because all the factors -- ΔH_{AO_x}, gram-atomic volume, z, and y -- are more favorable. Group III elements exhibit a similar trend, but their outputs are lower, because the less favorable z and y values predominate even though their ΔH_{AO_x}'s and gram-atomic volumes are more favorable. This relationship is best illustrated by comparing calcium and gallium, which have gram-atomic volumes of 25.8 and 11.8 cc and ΔH_{AO_x}'s of 152 and 259 kcal, respectively. In spite of these decided advantages, the thermal release of calcium is superior to that of gallium because of the more favorable z and y values. Because of the unusually high heat of formation of its oxide, aluminum occupies an anomalous position above magnesium.

The trend in enthalpies within the transition metal groups in the periodic table is also similar to that of the fluorides (Figure 1C). The first two groups, copper, silver, gold,* and zinc, cadmium, mercury, exhibit a decrease in enthalpy with

---

*Copper, silver, and gold are not shown on the plot in Figure 5 because their reactions yield positive enthalpies.

increasing atomic number. Their enthalpies are all very low because of their low ΔH_{AO_x}'s. The energies decrease both because the ΔH_{AO_x}'s decrease and because the gram-atomic volumes increase with increasing atomic number.

Within Group IVB (titanium, zirconium, and hafnium), Group VB (vanadium, niobium, and tantalum,) and Group VIB (chromium, molybdenum, and tungsten) the enthalpies increase with atomic number because their gram-atomic volumes and the heats of formation of their oxides become more favorable. In comparing one group with another, however, the normalized enthalpies decrease with increasing group number. The reasons for this differ between Groups IV and V and between Groups V and VI. Even though the gram-atomic volumes and ΔH_{AO_x}'s of Group V are more favorable than those of Group IV, their energies are lower because of the predominant effect of the unfavorable z and y values. Whereas the gram-atomic volumes and the z and y values of Group VI are more favorable, the unfavorable ΔH_{AO_x}'s cause Group VI energies to be even lower than those of Group V.

Curves of the type shown in Figure 5 were drawn for the other oxides. Similar trends were exhibited, but the curves were displaced vertically because of the differences in the parameters of each oxide.

The volumetric and gravimetric enthalpies of the reactions of the various oxides with aluminum metal are shown in Figures 6 and 7, respectively. These curves appear as an inverted version of the curves in Figure 5 because the metals that act as effective reducing agents form oxides that are poor oxidizing agents and vice versa. Thus the maximum volumetric energy outputs occur with the oxides of nitrogen, arsenic, sulfur, selenium, tellurium, the transition metals (chromium, manganese, iron, cobalt, nickel, copper, molybdenum, ruthenium, silver, rhenium, and osmium), and lead. The gravimetric behavior is similar, with the notable exception of the alkali metals. They exhibit relatively high gravimetric outputs, but their volumetric outputs are relatively low because of their very low densities. These curves enable one to determine the best oxide that can be used with aluminum metal for applications involving different parameters. Similar curves were drawn for all the metals.

The volumetric and gravimetric enthalpies of 9636 reactions of the oxides are summarized in Tables 9 and 10, respectively. The most energetic reactions are in the upper left portion of the tables. The most effective oxidizers are on the left and the most effective reducing agents are on the top. The orders of efficacy mentioned previously are confirmed here.

Table 9

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH OXIDES
(In descending order from top to bottom and left to right)

	N_2O_5	RuO_2	NO_2	N_2O_4	RuO_4	Re_2O_7	N_2O_3	NO	N_2O	Ag_2O_2	OsO_4	SO_2	PbO_2	CuO	SeO_2	As_2O_5	Co_2O_3	Co_3O_4	CO_2	OsO_2	SO_3
BE	-7987	-8279	-7390	-7221	-7616	-7773	-6620	-6147	-6098	-6637	-6880	-6087	-6403	-6330	-6227	-6345	-6389	-6321	-6185	-6079	-5931
U	-6812	-6815	-6379	-6221	-6435	-6246	-5939	-5445	-5395	-5728	-5779	-5749	-5337	-5236	-5232	-5183	-5195	-5066	-5028	-5195	-4949
HF	-6732	-6717	-6314	-6158	-6359	-6153	-5879	-5406	-5357	-5676	-5716	-5479	-5274	-5180	-5191	-5125	-5124	-5006	-4977	-5046	-4903
AL	-6613	-6571	-6206	-6050	-6235	-5995	-5780	-5323	-5273	-5572	-5592	-5542	-5147	-5051	-5063	-4988	-4993	-4858	-4834	-4928	-4783
TH	-6123	-6003	-5612	-5445	-5795	-5505	-5477	-5117	-5072	-5289	-5261	-5183	-4836	-4799	-4827	-4734	-4723	-4611	-4604	-4712	-4588
ZR	-6266	-6152	-5902	-5750	-5685	-5562	-5510	-5105	-5055	-5297	-5266	-5180	-4827	-4728	-4765	-4647	-4630	-4493	-4495	-4633	-4489
NP	-6083	-5926	-5737	-5476	-5692	-5304	-5348	-4964	-4913	-5125	-5061	-4951	-4614	-4505	-4562	-4409	-4395	-4233	-4253	-4427	-4278
[illegible]	-5549	-5349	-5314	-5173	-5238	-4871	-5036	-4761	-4718	-4850	-4761	-4653	-4417	-4331	-4336	-4251	-4229	-4112	-4133	-4261	-4165
TI	-5541	-5757	-5610	-5457	-5553	-5137	-5242	-4681	-4830	-5018	-4936	-4814	-4496	-4387	-4452	-4266	-4257	-4104	-4131	-4320	-4172
MO	-5751	-5542	-5500	-5377	-5443	-5113	-5206	-4906	-4863	-5024	-4960	-4868	-4619	-4531	-4574	-4460	-4443	-4332	-4349	-4469	-4353
LA	-5359	-5128	-5180	-5026	-5051	-4687	-4891	-4653	-4612	-4715	-4616	-4506	-4297	-4219	-4276	-4141	-4119	-4010	-4033	-4180	-4072
SM	-5449	-5236	-5224	-5105	-5140	-4759	-4955	-4694	-4651	-4768	-4669	-4555	-4329	-4242	-4302	-4159	-4135	-4017	-4049	-4198	-4083
GD	-5412	-5194	-5191	-5078	-5104	-4719	-4926	-4670	-4628	-4740	-4637	-4521	-4279	-4212	-4274	-4128	-4104	-3986	-4012	-4171	-4056
TA	-5193	-5284	-5254	-5082	-5131	-4489	-4875	-4644	-4490	-4408	-4425	-4214	-3909	-3767	-3599	-3605	-3546	-3325	-3418	-3747	-3572
HO	-5363	-5145	-5154	-5036	-5063	-4683	-4896	-4649	-4607	-4713	-4610	-4495	-4290	-4196	-4257	-4114	-4099	-3974	-4001	-4157	-4044
PR	-5293	-5070	-5008	-4976	-4997	-4615	-4843	-4607	-4565	-4662	-4554	-4437	-4237	-4146	-4209	-4004	-4059	-3925	-3953	-4111	-4000
CE	-5276	-5045	-5074	-4956	-4974	-4578	-4821	-4585	-4542	-4636	-4522	-4400	-4192	-4106	-4173	-4021	-3994	-3876	-3907	-4073	-3960
SI	-5247	-4950	-5015	-4853	-4863	-4211	-4660	-4400	-4345	-4423	-4219	-4002	-3742	-3607	-3744	-3450	-3390	-3183	-3274	-3503	-3440
SC	-5366	-5131	-5164	-5018	-5044	-4025	-4869	-4612	-4566	-4673	-4356	-4426	-4207	-4107	-4179	-4014	-3976	-3857	-3891	-4071	-3950
MG	-5227	-4959	-5029	-4911	-4924	-4520	-4779	-4548	-4506	-4593	-4474	-4348	-4143	-4057	-4126	-3909	-3941	-3822	-3854	-4026	-3913
B	-4660	-5889	-5668	-5081	-5007	-3063	-5221	-4806	-4747	-4951	-4233	-4660	-4279	-4134	-4240	-3985	-3936	-3715	-3764	-4176	-3891
NB	-5178	-4763	-4889	-4714	-4701	-3923	-4543	-4272	-4213	-4261	-4005	-3753	-3512	-3368	-3529	-3191	-3121	-2895	-3010	-3385	-3217
CR	-4890	-4418	-4640	-4469	-4417	-3575	-4324	-4098	-4039	-4041	-3745	-3458	-3234	-3079	-3271	-2675	-2791	-2538	-2688	-3122	-2946
V	-4020	-4605	-4764	-4603	-4574	-3830	-4451	-4210	-4153	-4164	-3930	-3476	-3445	-3303	-3467	-3125	-3053	-2828	[illegible]	-3325	-3158
MN	-4329	-3817	-4165	-4015	-3906	-3079	-3924	-3783	-3729	-3659	-3335	-3043	-2890	-2750	-2943	-2598	-2476	-2250	-2397	-2414	-2657
ER	-4663	-3789	-4030	-3911	-3842	-3415	-3660	-3775	-3739	-3698	-3518	-3371	-3249	-3195	-3284	-3104	-3069	-2964	-3018	-3211	-3123
GA	-3994	-3421	-3844	-3715	-3567	-2666	-3650	-3455	-3500	-3376	-3008	-2685	-2565	-2420	-2637	-2212	-2120	-1882	-2050	-2509	-2352
[illegible]	-3976	-3197	-3815	-3630	-3421	-2104	-3558	-3463	-3317	-3217	-2702	-2728	-2126	-1924	-2249	-1611	-1464	-1103	-1392	-2067	-1682
CA	-3682	-3944	-3777	-3603	-3612	-3189	-3656	-3595	-3561	-3499	-3312	-3163	-3077	-3006	-3099	-2915	-2830	-2778	-2836	-3129	-2946
ZN	-3637	-3036	-3547	-3406	-3226	-2310	-3368	-3320	-3267	-3100	-2705	-2372	-2295	-2143	-2369	-1934	-1890	-1607	-1761	-2348	-2098
LI	-3586	-3269	-3535	-3467	-3353	-2901	-3426	-3389	-3334	-3265	-3056	-2894	-2921	-2747	-2852	-2650	-2610	-2503	-2560	-2782	-2697
P	-3591	-3049	-3517	-3383	-3210	-2400	-3349	-3307	-3257	-3102	-2742	-2846	-2342	-2234	-2433	-2049	-1967	-1763	-1911	-2323	-2186
PO	-3260	-2710	-3455	-3249	-3006	-1711	-3234	-3200	-3133	-2896	-2358	-1986	-1827	-1637	-1962	-1335	-1192	-854	-1135	-1913	-1622
FE	-3508	-2739	-3448	-3277	-3029	-1760	-3243	-3210	-3147	-2915	-2382	-1921	-1842	-1678	-1989	-1390	-1254	-934	-1198	-1845	-1661
SN	-3162	-2431	-3118	-2667	-2718	-1620	-2965	-2979	-2922	-2671	-2181	-1776	-1737	-1576	-1856	-1324	-1207	-935	-1160	-1729	-1565
GE	-3116	-2314	-3060	-2014	-2639	-1421	-2914	-2038	-2879	-2602	-2067	-1417	-1599	-1414	-1725	-1133	-1001	-697	-958	-1591	-1418
IN	-3152	-2386	-3018	-2886	-2650	-1672	-2667	-2912	-2859	-2617	-2168	-1905	-1769	-1624	-1673	-1401	-1299	-1061	-1255	-1759	-1613
[illegible]	-2884	-1777	-2856	-2649	-2294		-2694	-2764	-2695	-2313	-1534	-944	-948	-753	-1199	-347	-146	799	-115	-1035	-817
NI	-2655	-1986	-2835	-2678	-2366	-1057	-2698	-2759	-2696	-2376	-1792	-1304	-1309	-1125	-1463	-823	-679	-357	-641	-1327	-1150
C	-2884	-1694	-2221	-2430	-2229	-407	-2660	-2738	-2667	-2271	-1515	-848	-905	-661	-1126	-236	-24	434		-958	-735
CO	-2790	-1908	-2777	-2420	-2300	-975	-2646	-2715	-2654	-2322	-1729	-1236	-1245	-1060	-1403	-755			-573	-1367	-1090
BA	-2207	-2194	-2519	-2450	-2322	-1906	-2467	-2414	-2405	-2330	-2108	-1951	-1927	-1867	-1974	-1776	-1737	-1645	-1714	-1921	-1655
SR	-2968	-2652	-2954	-2445	-2767	-2339	-2685	-2000	-2869	-2739	-2523	-2365	-2325	-2259	-2364	-2106	-2127	-2031	-2098	-2105	-2233
SC	-2313	-1457	-2385	-2204	-1865	-664	-2260	-2384	-2326	-1954	-1366	-898	-934	-777	-1092	-531	-414	-168	-391	-371	-617
AS	-2287	-1408	-2322	-2179	-1632	-556	-2238	-2367	-2308	-1927	-1324	-842	-899	-710	-1047		-277	24	-253	-924	-760
CD	-2249	-1531	-2262	-2140	-1869	-655	-2212	-2229	-2277	-1945	-1444	-1059	-1079	-937	-1207	-707	-599	-364	-577	-1103	-967
CS	-1667	-343	-1787	-1606	-1070	507	-1732	-1975	-1905	-1333		294	121	368	-153	820	1051	1519	1047		213
TE	-1576	-636	-1072	-1537	-1133	195	-1641	-1854	-1790	-1328	-668	-159	-251	-77	-438	226	374	678	383	-323	-165
NA	-1608	-1243	-1644	-1591	-1440	-1010	-1633	-1776	-1735	-1502	-1259	-1095	-1132	-1042	-1158	-949	-907	-818	-690	-1113	-1053
CU	-1730	-649	-1820	-1470	-1222	117	-1776	-1988	-1925	-1420	-684	-173	-251		-420	151	273	523	263	-312	-176
SE	-1227	-109	-1365	-1218	-731	859	-1356	-1628	-1565	-1008	-229	380	231	433		797	978	1341	974	125	302
BI	-1606	-828	-1684	-1570	-1229	-250	-1658	-1845	-1794	-1387	-632	-448	-495	-381	-628	-191	-102	270	-90	-535	-428
IR	-1034	446	-1227	-1046	-417	1763	-1225	-1561	-1489	-807	191	1012	763	1025	444	1542	1779	2284	1740	597	816
RU	-1397		-1504	-1347		1286	-1516	-1600	-1748	-1108	-169	409	491	656	106	1130	1373	1860	1355	360	477
RH	-1111	254	-1279	-1113	-538	1242	-1277	-1582	-1520	-884	77	715	537	746	290	1125	1315	1690	1303	416	594
S	-1703	-583	-1669	-1721	-1231	1525	-1631	-2049	-1951	-1453	-635		-117	1117	-347	1409	1554	1830	1541	-205	
K	-945	-579	-1008	-962	-770	-427	-1016	-1199	-1156	-875	-593	-484	-499	-462	-537	-404	-378	-325	-373	-511	-476
HG	-703	157	-850	-776	-316	895	-877	-1163	-1110	-599	60	535	412	508	225	845	980	1246	977	322	459
TL	-637	-354	-920	-860	-613	13	-933	-1116	-1081	-757	-390	-141	-187	-102	-282	39	105	238	112	-224	-145
CS	-597	-327	-689	-621	-420	-222	-711	-909	-875	-535	-339	-264	-276	-251	-305	-210	-191	-154	-168	-287	-263
RB	-732	-434	-821	-750	-553	-303	-641	-1056	-1017	-663	-446	-454	-368	-337	-403	-286	-263	-217	-250	-381	-350
AG	-157	628	-315	-219	171	1214	-367	-757	-695		478	894	773	906	603	1144	1260	1483	1253	584	600
AU	422	1993	107	243	1001	3209	-9	-519	-449	408	1507	2361	2019	2274	1661	2776	3037	3524	2980	1795	1595

Table 9 (cont.)

	ReO_3	MnO_2	TcO_2	CrO_3	NiO	HgO	MoO_3	MoO_2	WO_2	Fe_2O_3	GeO_2	CoO	WO_3	Fe_3O_4	FeO	SnO_2	As_2O_3	Sb_2O_5	Bi_2O_3	CO	Na_2O_2
BE	-6011	-6194	-5831	-5799	-5880	-5112	-5528	-5467	-5646	-5355	-5118	-4928	-5045	-4939	-4709	-4874	-4525	-4507	-4480	-4384	-4564
U	-4881	-4845	-4939	-4749	-4673	-4390	-4397	-4306	-4374	-4205	-4051	-3947	-3965	-3890	-3758	-3912	-3727	-3752	-3737	-3774	-3685
HF	-4829	-4785	-4703	-4702	-4621	-4361	-4353	-4252	-4326	-4164	-4015	-3955	-3929	-3857	-3730	-3790	-3703	-3720	-3715	-3755	-3660
AL	-4693	-4624	-4671	-4572	-4473	-4264	-4210	-4111	-4166	-4015	-3874	-3829	-3786	-3715	-3599	-3636	-3591	-3623	-3611	-3609	-3537
TH	-4490	-4406	-4450	-4395	-4297	-4171	-4086	-4000	-4039	-3923	-3810	-3777	-3737	-3680	-3584	-3613	-3579	-3607	-3596	-3650	-3532
ZR	-4360	-4237	-4378	-4260	-4121	-4042	-3878	-3767	-3791	-3679	-3559	-3545	-3467	-3406	-3314	-3372	-3347	-3391	-3362	-3477	-3271
NP	-4117	-3989	-4158	-4024	-3854	-3670	-3615	-3489	-3505	-3403	-3296	-3307	-3197	-3181	-3066	-3049	-3136	-3191	-3185	-3314	-3038
TB	-4032	-3900	-3971	-3964	-3833	-3852	-3656	-3565	-3579	-3501	-3416	-3417	-3344	-3299	-3234	-3234	-3269	-3308	-3302	-3393	-3204
TI	-4000	-3818	-4062	-3919	-3734	-3792	-3603	-3375	-3394	-3293	-3193	-3217	-3095	-3042	-2976	-2950	-3057	-3116	-3110	-3251	-2954
HO	-4239	-4132	-4240	-4166	-4051	-4064	-3866	-3781	-3906	-3714	-3420	-3605	-3551	-3502	-3425	-3439	-3439	-3471	-3462	-3531	-3335
LA	-3942	-3611	-3995	-3687	-3757	-3794	-3598	-3514	-3525	-3456	-3381	-3334	-3315	-3274	-3216	-3214	-3251	-3287	-3281	-3370	-3189
SM	-3963	-3602	-3948	-3625	-3742	-3787	-3569	-3470	-3497	-3414	-3330	-3341	-3262	-3219	-3158	-3155	-3202	-3243	-3236	-3337	-3132
GD	-3914	-3771	-3647	-3656	-3713	-3767	-3592	-3449	-3459	-3508	-3310	-3319	-3238	-3194	-3137	-3130	-3183	-3224	-3219	-3320	-3112
TA	-3272	-2900	-3032	-3222	-2890	-3289	-2653	-2455	-2397	-2374	-2314	-2443	-2179	-2139	-2138	-2011	-2366	-2472	-2476	-2748	-2172
ND	-3904	-3766	-3953	-3849	-3711	-3763	-3545	-3455	-3464	-3395	-3319	-3377	-3249	-3208	-3150	-3144	-3194	-3234	-3229	-3327	-3126
PR	-3869	-3719	-3910	-3807	-3667	-3731	-3605	-3416	-3424	-3358	-3285	-3295	-3216	-3176	-3121	-3113	-3167	-3208	-3203	-3303	-3099
CE	-3813	-3662	-3847	-3763	-3613	-3693	-3049	-3356	-3392	-3278	-3225	-3247	-3154	-3115	-3062	-3050	-3115	-3158	-3154	-3262	-3041
SI	-3184	-2789	-3299	-3108	-2740	-3202	-2678	-2395	-2339	-2323	-2271	-2394	-2147	-2111	-2113	-1974	-2329	-2430	-2438	-2699	-2146
SC	-3789	-3622	-3750	-3735	-3570	-3668	-3394	-3291	-3293	-3228	-3152	-3174	-3074	-3032	-2980	-2960	-3047	-3094	-3061	-3215	-2962
MG	-3742	-3604	-3820	-3711	-3549	-3655	-3398	-3303	-3306	-3245	-3175	-3174	-3103	-3064	-3014	-2999	-3073	-3118	-3113	-3227	-2996
B	-3620	-3285	-3716	-3543	-3234	-3512	-2058	-2758	-2719	-2653	-2578	-2684	-2436	-2385	-2362	-2251	-2147	-2667	-2618	-2917	-2332
NB	-2892	-2469	-3068	-2856	-2493	-3025	-2268	-2045	-2007	-2017	-1981	-2132	-1848	-1818	-1643	-1592	-2105	-2220	-2227	-2534	-1895
CA	-2555	-2059	-2738		-2122	-2812	-1628	-1693	-1594	-1629	-1415	-1820	-1470	-1647	-1504	-1309	-1826	-1961	-1972	-2332	-1581
V	-2820	-2348	-3011	-2800	-2433	-2982	-2234	-2031	-1951	-1965	-1933	-2094	-1901	-1772	-1601	-1648	-2066	-2182	-2189	-2499	-1855
[illegible]	-2296		-2815	-2295	-1903	-2597	-1743	-1541	-1441	-1499	-1485	-1679	-1359	-1342	-1398	-1223	-1698	-1823	-1935	-2183	-1472
EA	-2955	-2777	-3086	-2960	-2776	-3029	-2675	-2591	-2571	-2555	-2523	-2573	-2465	-2444	-2431	-2390	-2525	-2576	-2377	-2725	-2438
GA	-1995	-1437	-2205	-1971	-1542	-2354	-1396	-1182	-1063	-1136	-1150	-1370	-1020	-1010	-1069	-887	-1428	-1306	-1580	-1968	-1190
H	-1251	-432	-1644	-1340	-663	-2001	-421	-215		-177	-251	-612		-67	-256	175	-758	-980	-1017	-1584	-420
CA	-2776	-2508	-2872	-2768	-2605	-2874	-2413	-2431	-2408	-2396	-2472	-2427	-2317	-2290	-2293	-2247	-2391	-2443	-2485	-2600	-2303
ZN	-1645	-1179	-1956	-1722	-1291	-2149	-1163	-954	-831	-914	-937	-1164	-813	-807	-594	.698	-1242	-1381	-1398	-1708	-991
LI	-2512	-2313	-2671	-2510	-2352	-2656	-2244	-2157	-2127	-2127	-2108	-2176	-2050	-2035	-2039	-1981	-2157	-2215	-2219	-2366	-2057
P	-1823	-1387	-2068	-1651	-1476	-2218	-1358	-1177	-1078	-1139	-1150	-1337	-1041	-1032	-1096	-920	-1393	-1514	-1528	-1624	-1176
[illegible]	-1019	-205	-1034	-1100	-446	-1743			667	405	-53	-414	490	463	-75	654	-628	-830	-959	-1423	-252
FE	-1096	-721	-1671	-1160	-543	-1619	-815	-115	277		-158	-515	181			317	-692	-865	-912	-1454	-335
SN	-1064	-424	-1610	-1134	-602	-1729	-693	-243	-73	-212	-272	-573	-129	-137	-274		-721	-891	-915	-1407	-412
GE	-855	-125	-1277	-941	-342	-1619	-231	2310	2550	2303		-349	2304	2261	-23	2400	-533	-722	-750	-1293	-196
IN	-1169	-522	-1672	-1227	-760	-1753	-668	-449	-310	-419	-463	-717	-3.9	-342	-453	-223	-838	-964	-1009	-1452	-569
RE		1757	508	-164	1260	-1201	1328	1802	2229	1603	1678	933	1825	1761	1395	2002	516	-68	-131	-673	1079
NI	-543	252	-672	-667		-1410	99	400	628	423	324	-60	491	469	276	630	-282	-485	-516	-1103	92
C	117	1345	-605	-59	690	-1146	981	1431	1823	1440	1241	643	1419	1624	1091	1656	270	-7	-52		801
CO	-475	355	-912	-553	72	-1362	168	472	704	494	391		52	556	338	698	-229	-438	-466	-1060	151
BA	-1675	-1465	-1792	-1051	-1524	-1903	-1868	-1592	-1354	-1574	-1374	-1454	-1327	-1321	-1344	-1277	-1975	-1536	-1582	-1735	-1375
SR	-2053	-1861	-2146	-2062	-1891	-2244	-1825	-1745	-1711	-1723	-1716	-1790	-1666	-1656	-1671	-1509	-1795	-1853	-1859	-2044	-1697
SB	-319	328	-674	-408	130	-1114	202	431	690	448	371	47	498	482	331	604	-145		-343	-860	184
AS	-158	567	-668	-280	338	-1078	615	695	912	712	409	235	763	739	546	796		-207	-232	-623	354
CD	-501	64	-830	-580	-106	-1207	-31	180	332	200	136	-139	255	245	110	358	-304	-464	-486	-972	-20
CS	1136	2426	842	912	1924	-393	1654	2408	2826	2397	2159	1507	2192	2320	1942	2547	1046	743	490	-172	1615
TE	456	1241		323	960	-578	1618	1301	1532	1308	1186	745	1337	1304	1039	1451	505	294	257	-361	899
NA	-86	-667	-694	-891	-713	-1162	-876	-600	-554	-588	-402	-635	-557	-557	-594	-515	-746	-813	-923	-1045	
CU	345	[illegible]	[illegible]	256	764	-580	813	1042	1222	1051	958	633	1982	1058	288	1178	405	224	193	-366	726
SE	1649	2022	690	673	1657	-235	1692	2033	2335	2032	1861	1359	2040	1990	1707	2161	990	738	492	-58	1452
BI	-39	717	-318	-113	512	-721	568	789	958	801	717	419	638	818	651	935	202	-79		-538	509
IR	1833	3262	1656	1568	2679	68	2679	3171	3643	3146	2962	2139	3109	3020	2564	3262	1586	1253	1192	237	2212
RU	1845	2909	711	1204	2261	-193	2279	2752	3197	2735	2475	1745	2715	2635	2249	2870	1284	968	910	5	1881
RH	1574	2392	746	1183	2002	-43	2025	2380	2696	2372	2185	1655	2369	2313	2009	2492	1254	990	942	153	1738
S	1591	2330	1132	1441	2053	-535	2068	2324	2546	2319	2185	1787	2318	2278	2053	2407	1467	1253	1213	-307	1847
K	-357	-219	[illegible]	-377	-268	-569	-250	-205	-176	-200	-211	-274	-185	-186	-212	-161	-311	-354	-312	-514	-241
HG	1032	1729	626	900	1976		1508	1754	1958	1755	1437	1279	1767	1734	1532	1860	989	789	752	126	1345
TL	[illegible]	[illegible]	-63	63	370	-374	603	523	604	528	487	321	552	544	462	606	201	96	78	-272	330
CS	-177	[illegible]	-238	-192	-115	-336	-103	-71	-51	-68	-76	-120	-58	-59	-78	-42	-151	-182	-187	-301	-100
RB	-245	-138	-320	-269	-168	-436	-153	-114	-59	-110	-120	-173	-97	-98	-122	-77	-210	-248	-255	-301	-148
AG	1297	1661	626	1180	1671	359	1691	1695	2665	1895	1795	1490	1902	1673	1701	1978	1228	1050	1017	444	1538
AU	3080	[illegible]	4729	2748	3952	1071	3809	4279	4744	4260	3937	3147	4168	4070	3613	4297	2577	2220	2160	[illegible]	3222

Table 9 (cont.)

	Pb_3O_4	V_2O_5	Rb_2O_4	Ga_2O_3	Mn_2O_3	CdO	Sb_2O_3	Sb_2O_4	SrO_2	Cr_2O_3	Mn_3O_4	Ag_2O	Cu_2O	Cs_2O_3	PbO	V_2C_3	BaO_2	ZnO	In_2O_3	IrO_2	Nb_2O_5
BE	-4306	-4485	-5192	-4133	-4145	-4127	-4111	-3872	-3446	-3842	-3792	-3716	-3696	-3694	-2855	-3260	-3224	-4181	-4045	-3102	-3182
U	-3614	-3511	-3553	-3061	-3191	-3351	-3392	-3227	-2987	-2803	-2374	-3290	-3149	-3161	-2784	-2306	-2549	-2439	-3159	-2730	-2319
HF	-3504	-3444	-3535	-3042	-3172	-3333	-3364	-3212	-2973	-2787	-2361	-3280	-3136	-3150	-2408	-2302	-2543	-2435	-3142	-2726	-2317
AL	-3404	-3400	-3443	-2835	-3035	-3220	-3250	-3113	-2943	-2651	-2721	-3215	-3095	-3069	-2323	-2140	-2434	-2315	-3012	-2645	-2177
TH	-3407	-3368	-3451	-2050	-3112	-3260	-3241	-3162	-2047	-2793	-2852	-3240	-3103	-3115	-2780	-2392	-2579	-2449	-3090	-2732	-2408
ZR	-3281	-3033	-3284	-2570	-2748	-2632	-3033	-2905	-2581	-2324	-2446	-3077	-2881	-2899	-2521	-1864	-2223	-2087	-2744	-2544	-1816
NP	-3003	-2746	-3020	-2259	-2476	-2763	-2827	-2712	-2427	-2011	-2168	-2952	-2719	-2741	-2038	-1540	-2005	-1843	-2439	-2424	-1779
TB	-3227	-3016	-3193	-2665	-2794	-2675	-3017	-2613	-2462	-2491	-2561	-3061	-2692	-2907	-1597	-2120	-2311	-2262	-2739	-2591	-2151
TI	-3020	-2451	-3004	-2170	-2391	-2670	-2757	-2448	-2252	-1927	-2091	-2509	-2665	-2638	-2302	-1178	-1918	-1762	-2410	-2368	-1563
HO	-3375	-3217	-3337	-2877	-2990	-3144	-3178	-3064	-2446	-2691	-2754	-3163	-3042	-3035	-2409	-2332	-2518	-2431	-2975	-2560	-2340
LA	-3208	-3010	-3143	-2608	-2614	-2479	-3017	-2921	-2492	-2517	-2401	-3059	-2910	-2913	-2373	-2211	-2405	-2321	-2809	-2611	-2227
SM	-3187	-2915	-3134	-2547	-2722	-2611	-2955	-2656	-2494	-2404	-2391	-3020	-2842	-2858	-2254	-2060	-2305	-2203	-2720	-2555	-2057
GD	-3149	-2018	-3121	-2547	-2703	-2893	-2938	-2640	-2478	-2383	-2374	-3009	-2829	-2845	-2244	-2045	-2292	-2189	-2702	-2548	-2072
TA	-2417	-1870	-2434	-980	-1408	-1088	-2060	-1979	-1326	-715	-1361	-2117	-2132	-2171	-1724	-236	-1153	-673	-1496	-1993	-851
NB	-3154	-2035	-3132	-2000	-2729	-2012	-2954	-2656	-2406	-2425	-2507	-3119	-2644	-3350	-2218	-2064	-2374	-2226	-2737	-2542	-2117
PR	-3132	-2002	-3110	-2540	-2707	-2090	-2935	-2839	-2488	-2407	-2189	-3003	-2828	-2843	-2261	-2063	-2712	-2215	-2706	-2552	-2107
CE	-3087	-2880	-3067	-2551	-2036	-2633	-2879	-2766	-2420	-2337	-2416	-2568	-2782	-2790	-2712	-1994	-2248	-2145	-2640	-2515	-2026
SI	-2361	-1643	-2404	-1777	-1848	-1636	-2053	-1938	-1365	-621	-1125	-2099	-2116	-2158	-1490	-378	-1197	-942	-1532	-1987	-766
SC	-3027	-2733	-3003	-2357	-2518	-2764	-2796	-2704	-2097	-2143	-2278	-2913	-2711	-2730	-2170	-1812	-2174	-2003	-2525	-2450	-1857
ND	-3064	-2780	-3024	-2440	-2569	-2790	-2839	-2748	-2474	-2275	-2166	-2541	-2749	-2756	-2163	-1946	-2269	-2102	-2593	-2490	-1979
B	-2570	-1877	-2604	-1156	-1581	-2317	-2237	-2150	-1476	-843	-172	-2639	-2292	-2290	-1559	-306	-1273	-976	-1663	-2079	-837
BA	-2145	-1773	-2223	-726	-1143	-1703	-1530	-1736	-1096	-465	-919	-2364	-1950	-1975	-1356	-18	-944	-679	-1243	-1868	
CR	-1943	-677	-2000	-269	-759	-1011	-1500	-1535	-730		-424	-2216	-1746	-1795	-1146	448	-449	-341	-859	-1727	163
V	-2150		-2190	-769	-1118	-1708	-1802	-1755	-1070	-552	-443	-2342	-1923	-1946	-1131		-965	-718	-1210	-1649	-360
MO	-1817	-142	-1875	-347		-1731	-1473	-1451	-732	-139		-2113	-1657	-1703	-1114	260	-472	-342	-869	-1559	32
ER	-2541	-2235	-2563	-1974	-2105	-2306	-2302	-2311	-2034	-1841	-1944	-2577	-2358	-2378	-1926	-1621	-1377	-1776	-2124	-2218	-1640
GA	-1574	-409	-1649		-441	-1063	-1219	-1214	-438	221	-160	-1651	-1455	-1506	-939	568	-430	-124	-570	-1517	338
W	-1047	586	-1172	1480	700	-335	-577	-620	404	1777	1063	-1674	-1003	-1075	-570	2212	410	698	445	-1405	1765
CA	-2414	-2106	-2423	-1850	-1088	-2187	-2244	-2199	-1226	-1747	-1834	-2480	-2294	-2275	-1850	-1529	-1765	-1687	-2006	-2140	-1540
ZR	-1402	-878	-1463	350	-278	-895	-1024	-1057	-285	355	-15	-1623	-1312	-1355	-954	695	-301		-808	-1406	485
LI	-2107	-1880	-2217	-1764	-1725	-1653	-2014	-1980	-1477	-1447	-1576	-2311	-2057	-2081	-1669	-1261	-1559	-1449	-1755	-1942	-1315
P	-1527	-824	-1545	-190	-544	-1075	-1211	-1207	-839	-9	-309	-1698	-1425	-1472	-958	308	-519	-260	-653	-1408	113
MU	-868	1037	-1025	2020	1167	-702	-434	-887	1026	2314	1524	-1553	-861	-952	-386	2729	749	1230	877	-1111	2154
TE	-625	467	-1577	1331	724	-279	-500	-547	447	1555	1014	-1573	-922	-971	-431	1609	477	685	523	-1137	1523
SN	-928	273	-1657	934	401	-357	-549	-557	747	1144	674	-1529	-963	-996	-471	1460	231	597	226	-1120	1159
GE	-760	4712	-917	3239	2630	-135	-361	-414	2173	3595	2842	-1448	-793	-862	-338	3607	2103	2543	2395	-1037	3213
IX	-1039	70	-1131	587	144	-407	-675	-703	111	778	190	-1557	-999	-1057	-567	1064	39	354		-1170	625
RE	-218	4390	-412	3555	2840	1600	650	412	2185	3849	2407	-1164	-326	-419	324	4214	1675	2329	2046	-738	3461
NI	-570	622	-718	1609	1036	110	-122	-192	935	1927	1330	-1309	-609	-693	-173	2270	711	1153	809	-906	1651
C	-145	4011	-397	3160	2112	750	427	300	1886	3459	2479	-1131	-270	-365	175	3330	1429	2659	1744	-702	2132
CO	-527	976	-670	1770	1161	163	-71	-145	992	2009	1793	-1277	-569	-614	-139	2337	761	1207	869	-677	1914
BA	-1540	-2176	-1577	-924	-1100	-1514	-1301	-1374	-1080	-848	-990	-1758	-1482	-1508	-1206	-742		-928	-1136	-1511	-707
SA	-1849	-1843	-1879	-1771	-1809	-1422	-1663	-1665		-1178	-1280	-2022	-1729	-1743	-1839	-1010	-1296	-1192	-1436	-1743	-1062
SB	-304	831	-525	1369	917	152			843	1572	1143	-1111	-452	-519	-93	1837	475	1093	785	-757	1545
AZ	-209	1152	-867	1948	1240	359	133	52	1133	2051	1502	-1096	-374	-419	9	2350	409	1218	1023	-719	1948
CD	-332	976	-651	1109	608		-177	-430	610	1277	887	-1179	-570	-652	-206	1538	478	709	513	-837	1276
OS	540	2093	317	3964	2911	1898	1140	973	2440	4227	3236	-646	314	210	666	4531	2777	2730	2521	-274	3422
TX	178	1898	1	2375	1758	847	609	503	1627	2561	2001	-739	29	-51	393	2824	1334	1766	1524	-409	2433
NA	-837	-625	-808	-234	-372	-410	-680	-692	-373	-165	-279	-1153	-835	-865	-624	-47	-374	-263	-418	-954	-114
CU	132	1385	-29	1432	1464	700	498	412	1350	2048	1652	-752		-71	297	2318	1132	1487	1265	-397	2019
SE	560	2418	370	3241	2472	1363	1077	635	2280	3445	2736	-514	363	270	670	3716	1962	2387	2130	-188	3206
BI	-150	1182	-263	1677	1211	696	304	227	1128	1874	1418	-628	-223	-280	152	2071	935	1278	1040	-524	1787
IR	1031	3417	752	4735	3586	2636	1654	1883	3260	4844	3909	-345	703	598	1005	5267	2554	3293	3151		4896
RU	768	3717	508	4319	3218	1735	1371	1130	2930	4573	3544	-517	484	375	814	4672	2364	2985	2806	-155	4127
RH	818	4746	593	3583	2708	1627	1320	1169	2572	3743	3045	-407	504	466	848	4630	2110	2652	2476	-65	3513
S	1108	2675	909	3183	2625	1755	1517	1341	2674	3327	2918	-732	860	776	1069	3520	2126	2541	2402	-362	3143
K	-324	-112	-413	-2	-85	-232	-277	-290	-89	33	-33	-689	-394	-415	-278	98	-100	-29	-114	-510	58
HG	640	2043	485	4030	2101	1283	1058	948	1973	2789	3300	-304	469	390	719	2991	1480	2071	1895	-32	4657
TL	37	721	-54	999	767	377	203	217	732	1085	884	-516	-35	-81	175	1223	646	635	680	-311	1033
CS	-190	-8	-227	60	9	-75	-128	-139	5	93	45	-394	-217		-138	136	-4	46	-11	-314	108
KB	-268	-35		58	-12	141	-151	-149	-16	39	32	-497	-286	-307	-189	145	-28	33	-38	-399	111
AG	927	4166	760	4000	4173	1875	1270	1171	2064	2729	2336		732	659	930	2906	1806	2141	1999	226	2630
AU	1983	4493	1049	3620	4533	2982	2560	2332	4177	3827	4804	350	1509	1374	1695	6041	3420	3332	4093	522	5298

Table 9 (cont.)

	Ta_2O_5	SnO	MnO	Nb_2O_5	TiO_2	B_2O_3	P_2O_5	UO_3	SiO_2	Cs_2O_2	U_3O_8	CeO_2	GeO	Tl_2O	Tl_2O_3	Na_2O	PuO_2	K_2O	TiC	Rb_2O	ZrO_2
BE	-3070	-3011	-3010	-2612	-2590	-2592	-2580	-2525	-2437	[illegible]	-1922	-1770	-1708	-1678	-1547	-1448	-1365	-1310	-1239	-1217	-1040
U	-2124	-2942	-2219	-2662	-1451	-1408	-1612		-1677	-2094		-1018	-1359	-1445	-754	-1257	-654	-1034	-570	-990	-334
HF	-2125	-2947	-2212	-2659	-1662	-1415	-1615	-772	-1641	-2099	-1211	-1040	-1367	-1450	-787	-1068	-662	-1043	-602	-997	-362
AL	-1973	-2945	-2680	-2764	-1790	-1476	-1606	-1439	-1547	-2036	-1074	-896	-1396	-1404	-624	-990	-539	-986	-465	-951	-219
TH	-2267	-2462	-2304	-2493	-1674	-1673	-2034	-1934	-1857	-2154	-1464	-1332	-1470	-1530	-1139	-1237	-1029	-1164	-947	-1106	-790
ZR	-1649	-2164	-1837	-2240	-1217	-1440	-1600	-1677	-1315	-1921	-558	-666	-1186	-1326	-365	-952	-319	-874	-250	-874	
NP	-1364	-1976	-1564	-2789	-300	-1159	-1550	-1127	-1541	-17.3	153	-350	-1032	-1230	-38	-693	0	-773	85	-773	338
TB	-1957	-2246	-2614	-2438	-1650	-1773	-1660	-1781	-1671	-2061	-1312	-1167	-1403	-1467	-1005	-1154	-915	-1110	-840	-1059	-667
TI	-1464	-1926	-1504	-2648		-1799	-1332	-1073	-977	-1761	-509	-349	-1316	-1211		-466	-39	-753		-757	237
HO	-2150	-2435	-2257	-2233	-1693	-1959	-2014	-1919	-1847	-2138	-1490	-1370	-1501	-1538	-1198	-1266	-1095	-1194	-1017	-1129	-671
LA	-2052	-2343	-2157	-2471	-1795	-1476	-1706	-1947	-1798	-2047	-1454	-1347	-1483	-1522	-1190	-1257	-1097	-1190	-1026	-1129	-874
SM	-1999	-2247	-2014	-2297	-1571	-1715	-1639	-1480	-1415	-2006	-1259	-1134	-1373	-1446	-951	-1121	-865	-1036	-708	-1036	-632
GD	-1916	-2210	-2034	-2287	-1579	-1706	-1739	-1473	-1634	-2001	-1152	-1126	-1368	-1442	-945	-1117	-860	-1092	-793	-1036	-632
TA		-1750	-454	-1427	650	46	-463	39	157	-1316	719	1042	-494	-871	1512	-18	1409	-302	1300	-795	1661
ND	-1464	-2765	-2049	-2311	-1644	-1757	-1643	-1727	-1663	-2026	-1317	-1176	-1411	-1646	-1024	-1172	-938	-1117	-871	-1045	-724
PR	-1761	-2358	-2041	-2409	-1643	-1754	-1639	-1775	-1667	-2021	-1724	-1206	-1436	-1462	-1038	-1167	-952	-1121	-865	-1070	-740
CE	-1672	-2104	-1663	-2354	-1543	-1459	-1767	-1490	-1577	-1970	-1229		-1353	-1471	-939	-1105	-848	-1074	-700	-1029	-630
SI	-170	-1744	-258	-1440	413	-110	-551	-107		-1335	515	702	-458	-896	1204	-69	1135	-350	1124	-894	1540
SC	-1629	-2045	-1794	-2164	-1316	-1476	-1611	-1494	-1375	-1690	-1003	-602	-1233	-1349	-658	-956	-584	-942	-525	-933	-337
MG	-1620	-2163	-1917	-2325	-1471	-1423	-1720	-1594	-1534	-1953	-1190	-1061	-1328	-1412	-581	-1076	-603	-1052	-740	-1010	-563
B	-52	135	-438	-1414	670		-537	0	137	-1320	736	1047	-523	-905	1600	-41	1486	-326	1451	-408	1984
NB	557	-1704	-267	-1907	1372	473	-307	400	541	-1207	1151	1478	-349	-802	2016	313	1643	-229	1806	-724	2334
CR	673	-836	117	-1197	1345	617	4	461	737	-1148	1277	1601	-311	686	2124	355	1971	-77	1912	-99	2434
V	-1	-1073	-376	-1367	638	218	-348	712	327	-1192	847	1134	-437	-811	1592	-16	1489	-276	1459	-758	1907
MN	4.9	-421		-1101	999	528	-26	418	527	-1025	974	1201	-238	-668	1606	211	1591	-116	1547	-226	1961
[illegible]	-1529	-1870	-1428	-1609	-1288	-1403	-1539	-1784	-1315	-1764	-1060	-986	-1232	-1333	-654	-1021	-797	-1012	-751	-691	-637
GA	727	-811	494	-765	1333	715	-59	499	807	-883	1274	1531		-585	1964	470	1668	9	1629	-122	2249
H	2465	4	1592	-631	3347	4135	1153	-674	2214	-503	2654	3311	420	-300	4077	1513	3699	444	3140	223	4295
CA	-1863	-1782	-1539	-1843	-1217	-1331	-1436	-1315	-1267	-1704	-1027	-940	-1195	-1700	-814	-787	-743	-995	-721	-919	-613
ZN	67.	-431	397	-474	1373	403	259	784	849	-733	1331	1571	-28	-626	2000	445	1684	64	1641	-71	2245
LI	-1179	-1570	-.06	-1361	-944	-1050	-1214	-1068	-1017	-1565	-779	-645	-1071	-1175	-551	-406	-510	-840	-478	-632	-355
P	453	-669		-1600	416	445		434	527	-903	924	1145	-192	-616	1485	243	1414	-69	1304	-190	1727
IN	3005	364	1560	-439	3900	2474	1472	2702	2445	-425	3295	3776	612	-245	4590	1700	4161	601	3962	351	4764
FE	2165	167	1897	-676	2746	2474	1093	1431	1945	-462	2871	2774	451	-273	3346	1027	3107	475	2990	248	3556
SN	1674		1004	-415	2250	1499	813	1472	1571	-659	2254	2361	339	-304	2850	946	2642	382	2561	142	3071
GE	3765	1071	3644	-408	4279	3431	2476	3472	3445	-303	1864	4166	1542	-221	4699	2167	4392	1395	2262	1046	4759
IS	1353	-193	757	-608	1753	1347	572	1124	1217	-572	1643	1900	131	-369	2303	467	2174	239	2121	77	2523
PT	4533	1102	3162	276	5399	3424	2403	3711	3649	-14	4364	5145	1172	160	6135	1703	5326	1016	5233	688	6241
NI	2409	363	1959	[illegible]	3187	2139	1325	2340	2247	-247	2702	3159	632	-123	3757	1309	3478	593	3340	740	3958
C	4116	957	2658	121	5144	3477	2156	3405	3545	28	4244	4807	972	76	5755	1747	5197	910	4915	602	5882
CO	2355	406	1767	-104	3237	2296	1378	2706	2325	-218	2451	3220	632	-103	3021	1743	3536	618	3405	391	4015
BA	-677	-1340	-791	-1231	-541	-431	-749	-425	-538	-1148	-407	-331	-18	-904	-227	-510	-203	-599	-181	-408	-65
SR	-430	-1231	-1048	-1047	-745	-972	-1634	-469	-823	-1352	-621	-540	-591	-1073	-425	-483	-396	-736	-374	-740	-310
SB	1968	340	1440	-132	2465	1424	1114	179	1641	-170	2255	2546	5.2	-77	2961	1112	2795	595	2724	374	3141
AS	2544	552	1033	-32	1140	2278	1465	2929	2337	-90	2612	3142	725	-14	3671	1314	3422	696	3315	455	3651
CD	1661	222	1598	-249	2534	1553	605	1425	1612	-265	2000	2243	457	-14	2623	955	2466	476	2327	235	2603
OS	4620	1986	3527	4.9	5721	4135	2757	4024	4179	435	4803	5337	1335	361	6238	2162	5676	1235	5403	679	6323
TK	3658	450	2268	315	3581	2706	1158	2458	2757	204	3254	3530	1008	199	4047	1414	3793	935	3070	642	4159
NA	10	-753	-122	-685	169	21	-145	20	44	-622	217	268	-217	-466	396		397	-147	405	-205	506
CU	2468	614	1909	261	4967	4204	1510	2225	2311	167	2685	2944	900	172	3344	1433	3171	848	3089	603	3495
SE	3521	1384	3001	679	577	3492	2437	3406	3529	460	4026	4419	1319	384	5057	2005	4700	1192	4524	867	5181
BI	2217	639	1627	116	2011	2038	1403	2903	2049	-32	2463	2712	769	79	3039	1296	2941	737	2867	510	3260
IR	5550	1919	4147	459	6597	4709	3240	4432	4705	713	5459	5999	1690	557	6354	2511	6330	1478	6021	1078	7005
RU	5154	1400	3616	768	6098	4827	2914	4704	4441	556	5094	5647	1515	447	6576	2722	5904	1342	5695	966	6640
RH	4251	1359	3290	807	4534	3775	2641	3493	3812	609	4215	4719	1474	492	5375	2182	4996	1323	4807	976	5484
S	3672	1714	3011	1035	4161	3358	2572	3713	3470	433	3771	4020	1590	673	4460	2182	4259	1433	4143	1108	4597
K	133	-150	57	-291	216	173	32	132	152	-246	241	263	-34	-281	343	106	344		349	-51	404
HG	3141	1308	2527	604	3610	2850	2136	2432	2917	530	3274	3504	1272	444	3980	1845	3782	1168	3680	519	4116
TL	1361	478	1653	163	1547	1297	931	1235	1241	67	1491	1611	597	108	1796	970	1745	592	1727	436	1904
CS	158	-80	103	-147	210	160	88	159	177		235	204	34	-127	304	138	306	57	309	15	347
RB	173	-37	109		244	175	60	174	101	-210	268	304	21	-169	355	147	356	49	361		408
AG	3022	1474	4519	900	3374	2815	2192	2776	2849	733	3158	3376	1405	608	3714	1924	3557	1293	3470	1011	3826
AU	6209	2761	4958	1655	7133	5514	8022	5985	5524	1303	6089	6611	3214	986	7475	3102	6691	1958	6593	1495	7492

Table 9 (cont.)

	Cs_2O	Al_2O_3	HfO_2	UO_2	Sc_2O_3	BaO	Li_2O	Al_2O_3	BeO	ThO_2	SrO	MgO	Pr_2O_3	Sm_2O_3	Gd_2O_3	Ce_2O_3	CaO	Er_2O_3	Nd_2O_3
BE	-1008	-965	*650	-637	-535	-397	-182	309		0	-182	-133	103	-66	-63	-48	272	204	65
U	-832	-131	43		109	-48	449	745	749	563	214	501	589	437	426	449	730	767	564
HF	-838	-178		-39	67	-70	308	723	482	515	186	450	547	397	387	409	688	719	521
AL	-601		155	103	213	11	435	841	866	654	281	603	668	520	507	531	805	848	645
TH	-934	-685	*482	-483	-403	-338	-142	265	0		-131	-39	82	-52	-50	-38	217	207	51
ZR	-741	250	369	302	414	126	605	937	1091	832	411	501	825	681	665	601	954	1010	806
NP	-659	555	723	627	749	310	894	1265	1525	1155	628	1158	1108	966	941	573	1230	1312	1094
TB	-901	-590	*617	-422	-348	-308	-116	247	19	15	-129	-73	89	-34	-32	-20	213	203	61
TI	-647	475	550	441	590	253	725	1052	1166	929	526	910	911	758	771	796	1021	1074	876
HO	-950	-797	*602	-596	-525	-418	-272	35	-185	-150	-253	-253	-59	-185	-180	-171	69	42	-90
LA	-963	-631	*652	-643	-550	-460	-343		-285	-236	-311	-335	-144	-261	-255	-247	-24	-49	-174
SM	-865	-537	*371	-379	-305	-232	-80	270	64	52	-100	-32	121		1	12	244	237	94
GD	-553	-534	*370	-377	-304	-221	-80	267	61	50	-101	-33	119	-1		11	241	233	92
TA	-346	2558	2347	2040	2271	1072	2208	2593	3632	2625	1557	2807	2368	2231	2164	2226	2458	2679	2384
ND	-409	-635	*466	-408	-399	-341	-171	171	-59	-49	-173	-138	27	-91	-58	-78	146	134	
PR	-413	-657	*490	-490	-423	-357	-196	144	-95	-78	-193	-158		-117	-113	-104	119	103	-27
CE	-573	-531	*472	-379	-305	-284	-90	253	44	35	-108	-46	105	-13	-11		224	216	79
SI	-380	2108	1975	1770	1926	939	1918	2217	3057	2776	1376	2407	2082	1956	1896	1948	2175	2353	2090
SC	-797	-193	-54	-62		-52	201	515	443	357	120	294	399	274	271	287	510	530	375
MG	-604	-479	*325	-735	-263	-255	-49	237	96	79	-76		144	26	27	38	264	256	118
B	-365	2769	2520	2224	2425	1096	2393	2635	3993	2796	1611	3017	2496	2351	2276	2345	2587	2839	2517
NB	-300	3129	2831	2531	2724	1308	2592	2854	4210	3044	1625	3290	2731	2590	2522	2591	2807	3066	2750
CR	-401	3220	2621	2621	2811	1375	2470	2917	4274	3119	1905	3354	2801	2670	2605	2665	2873	3132	2827
V	-324	2550	2357	2119	2257	1129	2226	2501	3521	2614	1601	2781	2375	2246	2183	2242	2459	2666	2390
MN	-222	2539	2363	2147	2300	1202	2242	2495	3387	2596	1654	2743	2378	2260	2202	2255	2455	2644	2392
ER	-555	-568	*451	-452	-402	-324	-230	35	-164	-142	-222	-212	-77	-168	-164	-158	17		-39
GA	-139	2662	2653	2410	2574	1365	2482	2714	3707	2651	1841	3022	2606	2492	2428	2482	2675	2881	2624
W	132	5631	4295	4372	4436	2216	4187	4315	6983	4837	2939	5325	4239	4126	3994	4100	4261	4699	4305
CA	-839	-548	*459	-491	-394	-351	-233	13	-172	-151	-225	-217	-89	-175	-171	-165		-17	-110
ZN	-90	2619	2626	2405	2552	1396	2467	2643	3597	2814	1656	2971	2585	2477	2417	2471	2651	2845	2604
LI	-733	-271	*160	-192	-142	-170		240	104	91	-27	38	137	53	53	62	222	215	110
P	-165	2161	2058	1895	2018	1137	2000	2235	2849	2284	1530	2391	2128	2023	1978	2021	2202	2344	2130
MO	234	6235	5397	4824	5102	2447	4576	4649	7504	5268	3215	5815	4606	4499	4454	4469	4613	5092	4601
FE	170	4425	4606	3657	3849	2055	3585	3737	5339	4059	2654	4352	3658	3556	3461	3540	3695	4002	3700
SN	85	3667	3086	3193	3365	1830	3174	3357	4653	3593	2374	3838	3243	3160	3080	3128	3311	3571	3295
GE	832	5523	5110	4704	4948	3036	4631	4637	6179	5056	3608	5357	4648	4560	4464	4560	4652	4957	4677
IN	25	3690	2882	2659	2802	1598	2493	2837	3821	3037	2057	3203	2795	2696	2633	2688	2853	3052	2810
RE	466	6118	6622	6174	6505	3091	5720	5715	9494	6569	4001	7314	5669	5598	5413	5555	5553	6267	5790
NI	215	4925	4626	4034	4231	2244	3917	4049	5876	4432	2867	4784	3975	3876	3770	3656	4003	4346	4025
C	421	7659	6449	5842	6151	2929	5446	5459	9015	6256	3605	6949	5423	5327	5152	5288	5397	5979	5524
CO	264	4994	4468	4092	4300	2279	3969	4074	5947	4487	2926	4844	4024	3925	3918	3905	4049	4397	4075
BA	-557	-7	46	30	70		166	344	264	240	125	206	267	204	202	210	330	329	254
SR	-662	-276	*233	-238	-214	-218	-141	-15	-105	-99		-129	-69	-112	-111	-108	-24	-34	-80
SB	265	3744	3465	3240	3384	1999	3219	3375	4424	3575	2503	3774	3294	3204	3136	3196	3335	3557	3322
AS	325	4666	4270	3929	4112	2209	3434	3963	5516	4292	2894	4593	3891	3798	3704	3781	3930	4223	3934
CD	193	3365	3134	2919	3052	1621	3027	3091	3093	3752	2288	3419	3011	2922	2961	2918	3056	3253	3033
OS	651	7977	6933	6251	6597	3278	5940	5817	9171	6610	3769	7293	5797	5715	5541	5674	5759	6331	5897
TE	495	5018	4495	4255	4432	2554	4133	4237	5786	4584	3169	4890	4174	4090	3994	4072	4192	4501	4220
NA	-209	600	623	595	633	453	490	631	836	767	600	757	769	717	710	720	810	835	762
CU	457	4084	3817	3572	3711	2278	3525	3647	4706	3672	2769	4076	3583	3505	3433	3493	3614	3840	3614
SE	654	6258	5646	5169	5406	4405	4957	5073	7139	5515	3733	5948	4963	4884	4759	4856	4957	5360	5029
BI	379	3622	3477	3340	3491	2131	3318	3447	4640	3659	2623	3841	3584	3303	3236	3292	3419	3632	3411
IR	810	8794	7629	6873	7229	3045	6395	6329	9999	7214	4596	7961	6321	6248	6058	6202	6264	6868	5434
RU	721	8375	7366	6539	6468	3456	6102	6045	9580	6899	4377	7639	6044	5966	5784	5923	5997	6595	6151
RH	743	6609	5647	5470	5498	3181	5215	5262	7484	5790	3938	4243	5208	5132	5002	5104	5195	5617	5280
S	872	5281	4920	4627	4776	3011	4496	4557	5982	4855	3598	5152	4517	4451	4364	4433	4523	4800	4501
K	-60	453	469	455	476	398	513	537	581	555	470	544	560	536	527	532	590	594	555
HG	682	4768	4540	4165	4312	2694	4071	4157	5377	4443	3239	4685	4108	4036	3955	4021	4124	4381	4146
TL	348	2114	2068	1985	2046	1492	2036	2167	2431	2184	1754	2227	2165	2040	2023	2047	2146	2219	2109
CS		379	391	362	397	340	424	444	460	451	397	443	457	436	434	437	0	460	453
RB	-17	450	466	432	470	393	402	575	559	537	465	528	542	516	514	518	0	572	536
AG	805	4315	4087	3677	3992	2642	3417	3934	4906	4113	3140	4292	3856	3793	3729	3782	0	4078	3885
AU	1152	9677	8840	7300	7654	3159	5475	6773	+	7622	5113	9317	6785	6727	6504	6682	0	7312	6895

Table 10

GRAVIMETRIC ENTHALPIES OF REACTIONS OF METALS WITH OXIDES
(In descending order from top to bottom and left to right)

	NO_3	N_2O_5	NO_2	N_2O_4	N_2O_3	NO	N_2O	B_2O_3	CO	NaO_2	SO_3	CO_2	RuO_4	SO_2	MoO_5	InO	SO	SiO	K_2O_4	CrO_3	Li_2O_2	MoO_4	K_2O_3
BE	[illegible]	-8703	-8680	-8576	-4898	-4299	-3120	-1606	-3230	-3151	-3112	-3190	-2635	-2492	-2601	-1695	-2452	-2331	-2524	-2358	-2195	-2094	-2042
LI	-4248	-3954	-3774	-3874	-3803	-3746	-2794	-1128	-2769	-2673	-2650	-2457	-2333	-2278	-2260	-1613	-2231	-2073	-2207	-2038		-1838	-1807
AL	-3943	-3909	-3903	-3250	-3221	-3251	-2659	-785	-2310	-2244	-2197	-2150	-2020	-1950	-1619	-1506	-1923	-1788	-1650	-1403	-1397	-1546	-1521
MG	-3207	-3048	-3129	-3651	-3030	-3065	-2380	-608	-2294	-2178	-2116	-2089	-1933	-1922	-1895	-1514	-1908	-1778	-1842	-1454	-1438	-1562	-1530
B	-3765	-3423	-3865	-3460	-3247	-3348	-2304		-2108	-2098	-1940	-1435	-1803	-1661	-1649	-1389	-1712	-1529	-1570	-1744	-823	-1213	-1197
SC	-2790	-2617	-2642	-2807	-2567	-2448	-2114	683	-1937	-1445	-1892	-1731	-1735	-1437	-1624	-1416	-1678	-1570	-1570	-1435	-1155	-1338	-1323
SI	[illegible]	-2874	-2681	-2787	-2776	[illegible]	-2104	-54	-1814	-1727	-1665	-1584	-1517	-1458	-1495	-1337	-1554		-1395	-1193	-725	-1077	-1047
CE	-2271	-2430	-2971	-2837	-2423	-2475	-2037	-600	-1843	-1779	-1752	-1659	-1701	-1614	-1605	-1421	-1655	-1540	-1568	-1440	-1206	-1355	-1341
TI	-1870	-2297	-2300	-2297	-2252	-2333	-1847	192	-1600	-1232	-1492	-1396	-1499	-1357	-1117	-1202	-1229	-1105	-1087	-1167	-678	-914	-911
P	-2542	-2042	-2148	-2074	-2101	-2262	-1693	263	-1337	-1326	-1169	-1007	-1249	-1034	-1656	-1195	-1202	-1087	-1005	-1212	-324	-748	-770
ZR	-2013	-1920	-1660	-1890	-1913	-1992	-1657	-617	-1395	-1742	-1303	-1213	-1383	-1205	-1217	-1247	-1314	-1121	-1177	-1059	-776	-1001	-907
V	-1808	-1703	-1741	-1737	-1762	-1848	-1460	64	-1133	-1659	-1018	-884	-1107	-627	-849	-134	-1105	-988	-908	-760	-265	-730	-727
CA	-1702	-1141	-1628	-1448	-1609	-1723	-1390	185	-1013	-918	-896	-756	-1017	-815	-842	-1093	-1013	-859	-807		-243	-623	-629
LA	-1348	-1319	-1344	-1551	-1350	-1421	-1259	448	-1046	-1013	-947	-921	-1041	-940	-551	-1090	-1012	-864	-920	-845	-664	-824	-824
C	-1525	-1630	-1720	-1641	-1712	-1905	-1329	1856		-379	-371		-717	-303	-359	-1039	-758	-895	-326	-22	905	-79	-111
BA	-1390	-1748	-1301	-1271	-1207	-1349	-1215	[illegible]	-978	-965	-939	-472	-923	-494	-607	-1064	-1031	-912	-585	-801	-618	-792	-787
SA	-1347	-1271	-1314	-1240	-1309	-1343	-1219	460	-991	-956	-929	-458	-933	-882	-894	-1062	-925	-902	-873	-785	-590	-765	-766
NA	-1176	-1512	-1604	-1490	-1589	-1750	-1381	132	-947	-954	-648	-720	-1013	-793	-851	-1093	-1016	-844	-817	-435	-279	-638	-647
AS	-1544	-1941	-1400	-1090	-1887	-1945	-1190	18	-966		-336	-770	-973	-619	-849	-1077	-907	-893	-809	-671	-341	-651	-656
CR	-1302	-1243	-1280	-1250	-1277	-1349	-1154	380	-970	-943	-916	-848	-979	-673	-894	-1052	-932	-902	-660	-779	-500	-761	-742
MO	-1267	-1233	-1270	-1241	-1267	-1346	-1139	-990	-973	-931	-915	-848	-975	-872	-635	-1050	-979	-704	-664	-781	-600	-763	-743
	-1298	-1174	-1232	-1197	-1229	-1357	-1126	110	-790	-740	-609	-880	-813	-449	-475	-905	-834	-851	-644	-519	-207	-512	-510
MZ	-1276	-1274	-1248	-1216	-1242	-1319	-1154	911	-932	-977	-670	-797	-933	-826	-841	-1030	-944	-829	-619	-731	-533	-714	-714
EA	-1176	-1127	-1148	-1178	-1153	-1271	-1097	375	-694	-965	-611	-780	-903	-806	-817	-999	-939	-764	-600	-725	-560	-711	-713
SA	-1264	-1233	-1209	-1244	-1209	-1406	-1146	710	-600	-744	-698	-469	-893	-443	-675	-998	-846	-898	-640	-409	-148	-402	-507
FC	-1233	-1048	-1144	-1109	-1169	-1316	-1067	730	-507	-490	-493	-756	-581	-369		-928	-675	-848	-374	-232	286		-240
SU	-1232	-1176	-1204	-1178	-1201	-1276	-1137	356	-921	-840	-649	-798	-937	-425	-639	-1020	-934	-415	-812	-737	-559	-722	-727
FR	-846	-1075	-1140	-1097	-1153	-1205	-1064	467	-577	-332	-464	-907	-667	-423	-559	-629	-556	97	-336	-274	184	-212	-225
SR	-187	-1073	-1140	-1092	-1149	-1203	-1041	637	-537	201	-464	-393	-653	-419	147	-500	-53	212	209	-258	690	220	262
S	-165	-1017	-1148	-1062	-1152	-1347	-923	1712	-218	918		758	-417		372	-595		-822	404	613	1249	518	481
TA	-1144	-1124	-1140	-1197	-1159	-1274	-1100	997	-549	-459	-834	-770	-437	-798	-111	-999	-936	-829	-792	-714	541	-700	-702
MC	-1117	-1123	-1147	-1131	-1159	-1275	-1090	769	-546	-455	-841	-779	-931	-805	-619	-1000	-910	-822	-739	-723	-566	-712	-711
GC	-1147	-1124	-1143	-1178	-1162	-1232	-1102	393	-690	-959	-614	-763	-733	-797	-611	-1000	-926	-867	-791	-713	-538	-623	-701
TA	-1121	-1052	-1060	-1048	-1001	-1167	-1024	7	-712	-431	-657	-561	-741	-417	-641	-940	-790	-524	-619	-509	-253	-503	-507
K	-417	-936	-1014	-964	-1019	-1111	-837	140	-564	-524	-491	-392	-571	-461	-488	-848	-634	-456		-361	-104	-354	
SN	-921	-832	-801	-866	-866	-1018	-850	478	-492	-442	-491	-275	-557	-471	-405	-843	-590	-601	-370	-251	78	-261	-273
L	-597	-945	-974	-956	-981	-1070	-547	291	-738	-710	-627	-423	-749	-458	-674	-904	-771	-656	-656	-583	-416	-576	-579
ZN	-1016	-931	-984	-947	-900	-1096	-934	197	-617	-562	-624	-413	-635	-489	-513	-887	-690	-773	-495	-375	-92	-377	-386
TN	-1009	-1044	-1077	-1056	-1040	-1147	-1038	926	-530	-801	-728	-717	-844	-746	-769	-960	-853	-371	-742	-668	-504	-657	-660
TR	-688	-790	-827	-746	-630	-927	-820	717	-347	-236	-235	-70	-499	-211	-259	-612	-471	-424	-224	-71	354	-28	-115
	-892	-749	-803	-681	-649	-949	-678	399	-454	-405	-364	-939	-525	-337	-372	-622	-557	-619	-345	-219	105	-232	-241
RB	-916	-853	-807	-873	-901	-973	-665	-157	-659	-630	-607	-590	-687	-581	-508	-656	-702	-610	-540	-506	-337	-502	-504
FE	-805	-890	-847	-848	-886	-957	-692	-154	-648	-419	-576	-531	-677	-571	-589	-650	-672	-612	-571	-498	-327	-494	-403
								-03	-647	-421	-620	-541	-673	-578	-597	-636	-687	-430	-577	-511	-359	-507	-511
US	-871	-827	-557	-736	-701	[illegible]	[illegible]	765	-456	-415	-330	-276	-519	-356	-735		-547		-367	-255	161	-264	-274
IN	-867	-734	-784	-746	-721	-868	-774	437	-272	-425	-197	-68	-303	-193	-219	-691	-392	-265	-188	-87	195	-130	-11
SR	-547	-626	-684	-696	-627	-826	-634	429	-354	-393	-240	-125	-447	-238	-278	-761	-478	-379	-254	-119	227	-139	-153
CR	-772	-446	-707	-793	-757	-595	-769	664	-329	-272	-234	-69	-437	-202	-247	-791	-460	-517	-214	-71	326	-36	-112
AS	-709	-690	-748	-731	-779	-931	-761	1155	-26	41	100	306	-197	161	37	-700	-255	-71	70	246	763	190	165
SF	-600	-824	-514	-646	-537	-710	-571	112	-253	-231	-232	-165	-227	-213	-232	-563	-352	-243	-219	-140	-15	-169	-178
AB	-498	-890	-531	-403	-541	-740	-568	415	-369	-310	-275	-140	-453	-252	-291	-788	-490	-352	-268	-133	213	-152	-164
AT	-760	-702	-748	-731	-772	-901	-758	710	-135	-36	-43	95	-245	-35	-72	-667	-207	-154	-53	75	426	43	24
TE	-811	-871	-408	-646	-510	-558	-541	800	-86	-57	-32	48	-229	-27	-54	-507	-133	-103	-36	39	241	21	17
CU	-708	-872	-478	-346	-402	-437	-524	293	-245	-213	-196	-107	-311	-175	-202	-624	-341	-247	-184	-101	110	114	-124
CN	-689	-430	-470	-841	-407	-578	-517	85	-168	-153	-140	-130	-231	-135	-149	-420	-222	-173	-140	-69	+	106	-111
CS	-280	-320	-301	-441	-413	-545	-457	761	-297	-143	-155	-19	-344	-140	-122	-725	-350	-206	-101	-26	437	9	-8
AC	-613	-557	-519	-478	-633	-743	-649	336	-99	-70	-63	-12	-182	-60	-85	-507	-213	-129	-71	-15	184	-14	-27
DI	-318	-273	-308	-784	-319	-509	-357	426	35	70	131	202	-93	102	67	-482	-103	3	85	179	430	151	137
AU	-210	-235	-207	-240	-313	-849	-374	688	-37	+	51	136	-131	35	+	-540	-174	-63	10	117	379	91	77
CK	-305	-298	-264	-747	-312	-870	-362	1006	1	60	111	286		111	55	-646	-205	-42	84	237	674	189	164
	-436	-338	-511	-444	-433	-503	-487	452	20	40	58	113	-35	59	39	-340	-53	2	50	104	282	90	82
MN	-117	-98	-115	-99	-125	-147	-168	475	51	28	130	228	-51	120	93	-489	-97	15	102	201	468	171	154
IA	-208	-153	-202	-173	-219	-170	-282	492	206	235	241	448	112	256	224	-322	59	143	239	319	538	290	277
HI	13	55	18	97	-1	-98	-79	709	-110	-91	-78	-23	-159	-70	-89	-424	-191	-120	-77	-26	101	-36	-43
PB	-268	-220	-284	-236	-243	-311	-286	390	78	97	113	167	22	113	94	-263	-4	57	104	155	297	141	137
AG	-25	-22	-87	-83	-57	-179	-140	136	-35	-25	-16	11	-44	-14	-24	-246	-78	-43	-18	9	78	3	+
TL	-107	-92	-104	-98	-111	-104	-139	3023	725	874	1017	1430	233	889	711	-682	74	406	764	1133	2587	907	832

Table 10 (cont.)

	MgO_2	Na_2O_2	Re_2O_8	Nb_2O_4	SeO_2	Rb_2O_4	MnO_2	As_2O_5	OsO_4
BE	-1024	-1765	-1780	-2288	-1826	-1669	-1595	-1840	-1490
LI	-1414	-1552	-1630	-1724	-1446	-1526	-1397	-1649	-1437
AL	-1240	-1275	-1451	-1184	-1626	-1322	-1151	-1326	-1406
MG		-1319	-1402	-1275	-1449	-1351	-1293	-1434	-1371
Z	-741	-873	-1177	-184	-1155	-1047	-758	-1071	-1092
SC	-1074	-1112	-1280	-963	-1273	-1188	-1017	-1228	-1218
SI	-448	-703	-1068	-214	-1671	-977	-793	-943	-1022
CA	-1134	-1159	-1269	-1044	-1290	-1217	-1073	-1257	-1290
TI	-454	-874	-763	-864	-1076	-865	-796	-1009	-1036
P	-414	-467	-848	200	-411	-736	-432	-695	-791
ZA	-760	-813	-1032	-55	-698	-934	-750	-932	-868
V	-747	-409	-809	4	-765	-732	-444	-642	-751
CR	-744	-401	-713	140	-688	-626	-455	-572	-677
LA	-467	-701	[illegible]	-530	-440	-800	-454	-736	-428
C	[illegible]	204	-815	2708	-404	-239	707	-43	-390
PR	-403	-660	-838	-481	-402	-763	-435	-716	-792
SA	-474	-635	-815	-481	-784	-748	-401	-729	-776
SB	-278	-828	-763		-474	-636	-385	-576	-487
NA	-314		-765	-81	-701	-647	-615	-605	-494
CE	-440	-634	-410	-449	-788	-745	-404	-726	-774
ND	-448	-643	-811	-463	-785	-767	-409	-729	-776
IN	-211	-337	-625	75	-477	-531		-478	-579
HF	-472	-546	-772	-381	-743	-704	-553	-650	-735
ER	-440	-603	-742	-437	-734	-702	-473	-692	-730
GA	-148	-300	-610	145	-444	-517	-364	-457	-560
YB	334	-54	-339	820	-354	-314	-36	-220	-373
SM	-446	-625	-734	-623	6787	-711	-573	-620	-740
FE	137	-79	-341	654	-395	-240	-52	-242	-418
GE	[illegible]	-51	57	1012	-395	157	-23	-248	-408
S	1134	764	134	2047	-100	201	744	443	-155
TB	-440	-548	-744	-416	-427	-692	-457	-670	-721
HO	-448	-651	-741	-439	-734	-701	-571	-680	-729
CD	-447	-549	-743	-404	-724	-691	-555	-649	-720
TA	-343	-346	-443	-38	-461	-521	-375	-475	-553
K	-112	-222	-442	114	-435	-400	-178	-343	-437
SN	47	-32	-417	389	-358	-320	-99	-244	-470
U	-411	-472	-441	-289	-411	-531	-497	-553	-411
ZN	-37	-219	-505	177	-454	-415	-192	-359	-363
TH	[illegible]	-352	-713	-381	[illegible]	-654	-525	-631	-483
TC	[illegible]	151	[illegible]	734	-234	-198	115	-88	-261
W	[illegible]	-59	-390	404	-331	-244	-13	-216	-344
HP	-371	-300	[illegible]	-194	-444	-515	-375	-462	-447
PU	-394	-341	-569	-154	-437	-508	-359	-474	-436
BA	-444	-414	-575	-249	-455	-519	-493	-449	-447
TM	3	-123	-307	258	-358	-315	-99	-248	-362
SR	179	39	-257	882	-717	-171	54	-97	-242
CU	188	31	-116	554	-253	-217	49	-128	-276
AS	204	67	-207	710	-226	-150	109		-252
SE	404	669	-69	1373		34	110	181	-47
AB	-72	-48	-258	98	-323		-77	-142	-336
RI	184	19	-328	561	-264	-248	37	-140	-256
TE	447	208	-140	741	-80	-54	218	44	-121
CU	223	173	-112	420	-78	-44	131	22	-108
CD	64	-3	-241	289	-196	-171	8	-108	-113
CS	-8	-61	-174	79	-148	-136	-44	-103	-150
AE	303	193		620	-170	-97	394	-45	-201
BI	190	80	-135	338	-91	-72	90	-34	-111
RH	802	272	-19	632	81	60	277	147	9
OS	443	318	-79	613	-18	3	225	40	
AU	612	340	-68	1147	18	48	352	180	-25
HG	330	161	-11	357	25	36	166	69	6
IR	417	207	-9	709	53	74	302	146	20
AG	449	341	128	718	184	199	192	242	152
PB	93	32	-135	202	-92	-78	39	-34	-107
AG	274	208	80	342	77	88	211	139	57
TL	74	61	-39	130	-29	-22	44	3	-39

	TcO_3	Co_2O_3	RuO_2	V_2O_5	MoO_3	CaO_2	Sb_2O_5	GeO	Tc_2O_7	K_2O_2	Re_2O_7	GeO_2	Co_3O_4	Rh_2O_3
BE	-1775	-1544	-1579	-1572	-1506	-1492	-1344	-1385	-2026	-1357	-1322	-1334	-1350	-1316
LI	-1580	-1383	-1439	-1348	-1330	-1275	-1215	-1284	-1704	-1209	-1202	-1192	-1213	-1219
AL	-1343	-1178	-1258	-1074	-1105	-1004	-1041	-1146	-1546	-1012	-1037	-970	-1029	-1074
MG	-1375	-1320	-1240	-1190	-1158	-1078	-1080	-1178	-1542	-1048	-1083	-1040	-1080	-1111
Z	-1025	-863	-1004	-597	-734	-506	-747	-937	-1216	-668	-760	-613	-714	-848
SC	-1190	-1459	-1143	-940	-946	-882	-951	-1064	-1333	-916	-952	-885	-937	-926
SI	-614	-808	-945	-557	-696	-478	-704	-895	-1109	-632	-722	-891	-676	-810
CA	-1237	-1103	-1175	-1010	-1042		-1005	-1096	-1350	-976	-1000	-949	-991	-1035
TI	-833	-467	-972	-698	-778	-537	-780	-928	-931	-630	-780	-490	-757	-763
P	-671	-476	-728	-270	-835	-198	-505	-724	-800	-409	-520	-754	-463	-638
ZA	-617	-816	-914	-664	-737	-616	-744	-881	-1013	-696	-754	-643	-723	-816
V	-645	-660	-699		-446	-255	-504	-700	-749	-422	-521	-774	-469	-623
CR	-549	-480	-626	-215	-350	-157	-432	-641	-657	-544	-456	-296	-304	-562
LA	-774	-716	-792	-605	-658	-574	-672	-782	-837	-634	-680	-610	-655	-732
C	-73	-5	-285	650	242	754	-2	-382	-179	195	-60	293	83	-267
PR	-745	-660	-759	-564	-620	-534	-638	-752	-706	-538	-647	-574	-627	-702
SA	-717	-460	-743	-536	-597	-504	-618	-739	-781	-575	-629	-549	-593	-687
SB	-574	-394	-638	-269	-390	-189	-450	[illegible]	-670	-544	-470	-332	-415	-573
NA	-573	-520	-648	-301	-418	-251	-474	[illegible]	-620	-339	-405	-358	-441	-586
CE	-714	-461	-740	-542	-600	-511	-620	-737	-777	-579	-630	-454	-602	-686
ND	-719	-464	-742	-548	-625	-518	-624	-738	-779	-593	-635	-440	-604	-629
IN	-471	-411	-559	-190	-509	-145	-377	-665	-584	-299	-509	-250	-343	-406
HF	-673	-416	-701	-486	-551	-484	-577	-702	-732	-531	-588	-509	-557	-649
ER	-473	-476	-700	-517	-571	-491	-591	-701	-726	-553	-601	-551	-574	-654
GA	-453	-386	-527	-137	-274	-87	-351	-556	-528	-265	-375	-221	-314	-482
YB	-211	-177	-337	211		274	-160	-408	-280	-12	-101	-8	-115	-320
SM	-441	-429	-709	-512	-570	-483	-592	-708	-737	-551	-607	-627	-574	-659
FE	-137	-206	-377	118	-73	165	-186	-366	-255	-42	-210	-27	-137	-701
GE	244	-190	-367	585	-47	625	-170		232	377	-205		-120	76
S	455	465	-111	1002	675	1056	422	39	419	608	360	649	503	143
TB	-643	-613	-690	-498	-555	-470	-578	-662	-716	-537	-589	-814	-540	-644
HO	-677	-624	-697	-514	-568	-487	-580	-700	-725	-550	-502	-832	-572	-653
CD	-640	-411	-699	-496	-557	-467	-574	-692	-715	-535	-584	-612	-569	-643
TA	-469	-417	-529	-233	-331	-195	-387	-563	-531	-321	-405	-297	-358	-401
K	-341	-297	-419	-102	-228	-66	-274	-453	-305		-247	-170	-244	-306
SN	-203	-198	-341	54	-44	98	-181	-396	-302	-90	-207	-47	-141	-323
U	-547	-506	-595	-388	-448	-362	-470	-598	-503	-436	-491	-413	-460	-551
ZN	-351	-302	-430	-64	-203	-43	-278	-469	-411	-200	-302	-161	-244	-402
TH	-623	-579	-459	-468	-523	-442	-549	-640	-673	-509	-558	-436	-533	-614
TC		-50	-227	280	40	333	-44	-306		72	-80	127	7	-223
W	-217	-173	-317	78	-57	121	-140	-374	-274	-68	-187	-27	-118	-302
HP	-477	-439	-521	-312	-377	-286	-415	-581	-522	-348	-428	-344	-304	-403
PU	-470	-432	-515	-307	-372	-281	-409	-535	-514	-343	-423	-330	-389	-487
BA	-455	-450	-528	-338	-396	-315	-428	-542	-525	-386	-430	-366	-409	-498
TM	-213	-208	-334	3	-112	40	-194	-383	-200	-115	-217	-77	-158	-318
SR	-35	-69	-213	102	35	198		-263	-149	25	-90	64	-25	-197
CU	-151		-214	182	27	226	-63	-314	-186	15	-114	[illegible]		-239
AS	-91	-51	-220	261	82	310	-45	-297	-140	66	-80	118	4	-217
SE	147	194	-14	611	368	669	170	-135	116	325	131	391	245	-43
AB	-145	-142	-221	-20	-35		-135	-262	-100	-88	-151	-66	-114	-219
RI	-147	-102	-256	170	14	214	-97	-323	-109	[illegible]	-124	51	-49	-248
TE	35	65	-94	356	196	309	63	-184	-7	169	57	217	113	-106
CU	17	37	-93	212	115	238	34	-134	-10	105	13	135	67	-80
CD	-119	-84	-193	92	-3	120	-79	-249	-145	-11	-101	19	-48	-193
CS	-109	-91	-149	-4	-50	9	-67	-183	-122	-52	-99	-36	-71	-151
AE	4	-17	-173	356	174	406	-14	-223	-46	152		205	88	-143
BI	-15	-12	-95	162	75	186	-11	-154	-43	67	-26	94	32	-103
RH	149	157	24	379	254	410	150	-56	110	236	120	273	188	
OS	83	104	-29	331	203	364	90	-109	50	186	69	224	138	-45
AU	149	192		556	343	606	178	[illegible]	123	310	135	368	237	-25
HG	85	97	17	223	154	241	[illegible]	-37	66	145	77	157	118	3
IR	159	175	34	411	278	444	164	-50	127	257	135	297	207	15
AG	279	284	164	483	371	508	271	79	253	350	247	388	307	-135
PB	-36	-21	-95	91	30	108	-20	-140	-57	25	-35	45		-101
AG	134	145	67	256	200	283	141	11	119	190	127	212	163	-51
TL	2	10	-32	73	39	82	10	-62	-8	36	1	48	22	-38

Table 10 (cont.)

	Rb_2O_2	SrO	TcO_2	Fe_2O_3	TcO_2	Ca_2O_4	As_2O_3	CuO	Sb_6O_{13}	V_2O_4	P_2O_3	Fe_3O_4	ReO_3	Mn_2O_3
BE	-1306	-1301	-1204	-1293	-1236	-1256	-1253	-1229	-1163	-1188	-1226	-1184	-1117	-1113
LI	-1191	-1238	-1141	-1195	-1135	-1156	-1151	-1127	-1055	-1018	-1036	-1054	-1010	-977
AL	-1034	-1163	-973	-988	-943	-1014	-947	-983	-903	-790	-797	-873	-877	-788
MG	-1074	-1168	-1025	-1010	-1038	-1058	-1014	-1027	-954	-879	-893	-937	-929	-963
B	-776	-1038	-672	-851	-710	-774	-448	-722	-618	-301	-243	-520	-600	-389
SC	-953	-1085	-892	-859	-894	-982	-845	-912	-834	-713	-705	-759	-617	-722
SI	-731	-872	-690	-752	-640	-742	-613	-700	-593	-300	-250	-499	-584	-380
CA	-900	-1107	-948	-925	-943	-986	-971	-959	-693	-836	-806	-869	-573	-804
TI	-704	-906	-636	-457	-747	-712	-714	-744	-602	-424	-471	-618	-669	-571
P	-589	-852	-443	-911	-509	-471	-439	-527	-814	-64		-796	-416	-172
ZR	-760	-949	-670	-443	-719	-765	-609	-735	-659	-494	-475	-602	-650	-526
V	-540	-828	-451	-357	-538	-465	-415	-524	-425		-114	-325	-428	-218
CR	-479	-762	-560	-377	-435	-407	-374	-662	-359	-51	1	-760	-356	-143
LA	-684	-856	-638	-877	-640	-498	-639	-471	-613	-497	-490	-570	-600	-518
C	-107	-880	66	311	-35	-180	49	-116	57	820	1077	368	19	617
PR	-658	-833	-694	-851	-639	-463	-601	-640	-581	-659	-845	-536	-578	-483
SR	-634	-825	-583	-510	-610	-497	-579	-622	-560	-426	-411	-510	-557	-454
NB	-494	-786	-398	-315	-440	-514	-339	-475	-375	-64	-53	-299	-387	-197
NA	-504	-795	-427	-331	-441	-532	-425	-896	-408	-153	-113	-314	-408	-223
CE	-637	-821	-556	-552	-612	-447	-543	-623	-564	-437	-421	-517	-561	-463
ND	-680	-822	-571	-487	-616	-450	-547	-627	-568	-445	-431	-523	-566	-470
HS	-815	-710	-339	-288	-364	-483	-339	-408	-314	-62	-21	-223	-325	
HF	-598	-756	-542	-823	-573	-400	-519	-584	-521	-380	-363	-468	-520	-411
ER	-608	-787	-501	-570	-547	-419	-559	-597	-362	-426	-413	-498	-540	-449
GA	-398	-711	-305	-305	-373	-824	-371	-488	-290	0	48	-184	-290	-87
MO	-219	-619	-85	53	-209	-257	-113	-318	-82	352	435	73	-129	293
SM	-610	-796	-500	-515	-597	-421	-557	-598	-539	-413	-399	-492	-538	-440
FE	-243	-861	-99		-239	-334	-135	-344	-94	229	294		-150	125
GE	-231	-364	235	835	-217	130	-118	-333	251	659	724	428	-138	531
S	318	-900	464	697	233	918	849	978	834	1087	1222	675	387	842
TB	-594	-782	-547	-503	-576	-407	-594	-584	-527	-404	-390	-481	-526	-430
HO	-604	-784	-559	-516	-545	-417	-564	-595	-539	-421	-408	-495	-538	-445
GD	-558	-771	-565	-500	-573	-406	-542	-585	-524	-400	-394	-478	-524	-427
TA	-326	-689	-389	-274	-401	-485	-354	-413	-335	-122	-71	-255	-340	-180
K	-318	-808	-241	-159	-330	-388	-238	-312	-231	-3	31	-144	-241	-69
SN	-230	-850	-141	-74	-219	-370	-139	-332	-135	164	214	-22	-150	71
U	-500	-700	-451	-803	-443	-415	-445	-493	-434	-305	-299	-385	-437	-335
ZN	-316	-830	-240	-198	-335	-352	-245	-317	-229	26	46	-133	-240	-49
TH	-564	-752	-519	-475	-547	-479	-515	-556	-501	-381	-356	-455	-501	-407
TC	-108	-420		139	-103	-162	[illegible]	-117	-1	396	448	145	-28	262
W	-208	-862	-119	-18	-189	-289	-111	-211	-119	185	215	-9	-131	91
NP	-439	-855	-387	-334	-434	-457	-388	-433	-370	-231	-212	-318	-378	-266
PU	-439	-889	-382	-330	-419	-451	-379	-428	-369	-227	-209	-314	-373	-262
BA	-449	-868	-402	-356	-435	-465	-409	-443	-390	-265	-246	-341	-393	-294
IN	-235	-456	-157	-95	-225	-371	-155	-237	-152	100	139	-55	-168	24
SB	-111		-25	74	-107	-190	-97	-116		248	292	80	-44	163
CO	-138	-519	-43	73	-132	-180	-41	-145	-43	266	343	81	-62	180
AS	-104	-417	-2	130	-101	-158		-115	-8	371	438	136	-26	246
SE	98	-412	224	402	49	23	226	74	205	713	811	395	174	433
AB		-401	-114	-59	-149	-188	-113	-166	-112	33	53	-53	-121	-6
BI	-148	-426	-53	63	-101	-193	-53	-154	-52	275	331	71	-71	170
TE		-415	99	277		-54	131	-12	93	447	570	229	69	330
CU	-4	-320	61	152	-4	-81	43		54	273	306	145	43	268
CD	-118	-423	-51	28	-118	-152	-97	-123	-50	163	195	34	-64	100
CS	-109	-990	-72	-32	-107		-71	-112	-72	32	46	-28	-70	4
RE	-77	-858	77	216	-49	-84	49	-81	77	459	528	218		329
BI	-38	-828	28	101	-38	-67	37	-46	25	221	250	105	-4	163
RH	97	-377	178	390	93	50	179	84	170	445	499	280	148	357
OS	84	-326	129	232	84		130	34	122	402	447	235	101	313
RU	107	-378	219	378	96	36	271	83	206	649	731	373	174	495
HG	67	-197	112	172	61	33	113	55	109	265	287	174	96	219
IR	111	-378	196	304	138	61	197	97	187	479	526	303	164	385
AU	221	-183	295	399	218	174	294	306	289	534	574	386	263	455
PB	-48	-282	-2	50	-67	-79	-1	-53	-3	135	154	54	-13	96
AG	109	-187	158	216	106	70	148	100	153	305	327	217	140	261
TL	-8	-159	20	51	-6	-22	31	-9	20	97	107	53	13	76

	SiO_2	Sb_2O_4	CoO	MoO_2	NiO	Mn_3O_4	Ag_2O_2	FeO
BE	-1109	-1076	-1057	-1109	-1046	-953	-1078	-1017
LI	-908	-979	-960	-994	-948	-837	-1010	-918
AL	-631	-838	-814	-830	-805	-667	-915	-771
MG	-756	-892	-872	-892	-862	-748	-949	-833
B	54	-560	-529	-591	-516	-276	-743	-867
SC	-571	-781	-760	-766	-759	-621	-669	-719
SI		-541	-511	-833	-499	-278	-721	-454
CA	-701	-841	-823	-835	-814	-709	-907	-788
TI	-316	-632	-600	-607	-599	-442	-768	-565
P	280	-374	-343	-295	-331	-91	-600	-384
ZR	-349	-617	-595	-584	-587	-449	-743	-656
V	94	-390	-362	-325	-342	-158	-592	-311
CR	197	-326	-290	-252	-285	-76	-547	-245
LA	-407	-595	-562	-559	-563	-466	-690	-640
C	1545	78	125	256	140	566	-337	214
PR	-366	-554	-539	-526	-532	-432	-665	-409
SR	-376	-532	-514	-501	-509	-402	-652	-485
NB	149	-352	-327	-290	-319	-136	-555	-281
NA	43	-373	-348	-312	-339	-160	-566	-302
CE	-342	-537	-521	-506	-515	-412	-652	-491
ND	-355	-542	-525	-514	-520	-420	-655	-497
HS	125	-292	-267	-227	-259		-496	-222
HF	-277	-495	-479	-461	-471	-361	-622	-447
ER	-342	-519	-504	-491	-468	-405	-629	-477
GA	219	-263	-237	-190	-227	-30	-496	-158
MO	686	-92	-63		-53	254	-359	-10
SM	-321	-514	-490	-484	-492	-302	-631	-470
FE	454	-111	-81	-16	-71	169	-386	
GE	805	-94	-67	396	-51	555	-380	-4
S	1557	435	478	614	400	860	-235	555
TB	-315	-503	-488	-474	-482	-344	-619	-460
HO	-336	-515	-501	-487	-495	-400	-627	-473
GD	-311	-501	-486	-471	-490	-341	-618	-458
TA	26	-311	-290	-256	-282	-132	-493	-251
K	150	-212	-190	-150	-183	-26	-342	-151
SN	372	-116	-90	-35	-82	115	-361	-43
U	-216	-415	-401	-392	-395	-295	-542	-373
ZN	208	-208	-185	-140	-176	-2	-422	-141
TH	-206	-470	-465	-450	-459	-364	-595	-438
TC	679	14	48	121	55	304	-297	102
W	391	-93	-69	-20	-61	134	-344	-27
NP	-136	-355	-340	-317	-334	-228	-494	-311
PU	-138	-351	-335	-313	-330	-225	-489	-307
BA	-183	-372	-368	-336	-353	-259	-498	-333
IN	267	-134	-112	-65	-104	64	-354	-70
SB	824		10	65	18	197	-272	53
CO	511	-27		63	8	220	-295	49
AS	653	11	41	113	50	287	-281	95
SE	1071	217	257	355	264	565	-153	318
AB	118	-102	-69	-59	-83	17	-197	-62
BI	409	-36	-8	53		210	-302	40
TE	690	104	132	204	141	363	-190	183
CU	400	66	85	131	91	293	-181	119
CD	293	-38	-19	23	-13	129	-244	15
CS	90	-65	-54	-33	-51	21	-146	-34
RE	723	94	114	192	124	365	-244	169
BI	334	34	52	93	58	187	-162	83
RH	609	176	190	259	206	391	-101	240
OS	573	130	158	213	161	340	-127	195
RU	948	213	246	338	256	525	-132	305
HG	351	114	128	143	133	237	-57	154
IR	655	193	217	290	224	409	-76	259
AU	676	257	308	368	314	473	37	345
PB	212	5	17	46	21	115	-148	40
AG	388	157	171	206	175	276		196
TL	138	23	31	48	34	87	-72	45

Table 10 (cont.)

	IrO_2	RhO	Ce_2O_3	Au_2O_3	SrO_2	OsO_2	WO_3	Cr_2O_3	SnO_2	Nb_2O_5	Sb_2O_3	PbO_2	Rb_2O_2	Sb_4O_6	W_3O_8'	W_2O_5	V_2O_3	Ga_2O_3	BaO_2	ZnO	Cu_2O	In_2O_3	TiO_2
BE	-1030	-971	-448	-474	-1039	-957	-915	-939	-937	-858	-852	-478	-861	-846	-844	-795	-836	-839	-755	-695	-697	-707	-755
LI	-957	-938	-838	-329	-837	-881	-877	-813	-818	-742	-767	-419	-707	-776	-766	-723	-716	-738	-681	-621	-653	-411	-620
AL	-855	-713	-742	-343	-737	-700	-793	-626	-691	-567	-679	-726	-647	-667	-644	-606	-535	-584	-562	-601	-578	-432	-414
MG	-934	-952	-838	-474	-734	-833	-754	-719	-796	-640	-727	-769	-739	-721	-704	-660	-635	-646	-629	-573	-621	-596	-542
B	-673	-426	-568	-492	-344	-488	-304	-165	-378	-172	-432	-433	-458	-426	-368	-341	-69	-210	-276	-197	-404	-345	176
SC	-620	-778	-732	-468	-673	-751	-652	-584	-691	-533	-640	-494	-655	-636	-611	-590	-504	-551	-538	-483	-561	-513	-400
SI	-652	-479	-543	-475	-357	-472	-301	-197	-372	-149	-420	-521	-445	-418	-363	-339	-94	-218	-279	-204	-400	-357	116
CA	-653	-818	-783	-744	-741	-799	-723	-603	-714	-635	-702	-704	-713	-697	-681	-650	-613	-542	-618	-566	-611	-536	-536
TI	-737	-412	-639	-487	-474	-438	-597	-392	-493	-348	-517	-589	-535	-447	-430	-409	-313	-384	-403	-348	-471	-337	
P	-525	-459	-437	-473	-153	-447	-235	-1	-218	35	-292	-405	-320	-287	-220	-223	94	-68	-140	-66	-306	-139	313
ZR	-639	-452	-612	-701	-835	-475	-505	-467	-493	-349	-518	-581	-531	-511	-478	-455	-359	-398	-413	-361	-473	-397	-274
V	-522	-490	-410	-568	-737	-452	-267	-69	-290	-70	-317	-414	-338	-309	-252	-235		-123	-182	-127	-320	-177	146
CR	-474	-448	-479	-428	-153	-904	-734		-196	31	-260	-368	-286	-256	-108	-170	79	-40	-122	-57	-281	-123	255
LA	-640	-419	-146	-452	-897	-497	-504	-438	-494	-411	-511	-563	-524	-508	-488	-447	-302	-429	-436	-399	-478	-424	-329
C	-227	-272	-30	-315	857	-130	232	756	274	770	82	-111	55	58	214	215	886	549	311	413	-48	275	1346
PR	-620	-424	-559	-430	-847	-471	-474	-402	-456	-377	-484	-539	-407	-491	-455	-439	-357	-397	-409	-370	-457	-376	-232
SR	-604	-173	-541	-427		-594	-490	-370	-490	-388	-467	-521	-477	-459	-431	-418	-322	-367	-382	-342	-438	-371	-231
NB	-433	-454	-336	-354	-143	-816	-247	-72	-224		-268	-384	-311	-271	-212	-197	-2	-100	-165	-107	-301	-163	212
NA	-530	-471	-413	-447	-213	-435	-263	-98	-297	-68	-304	-400	-329	-302	-249	-238	-25	-123	-184	-127	-315	-132	111
CE	-634	-490	-545	-428	-935	-457	-457	-302	-497	-357	-469	-425	-463	-466	-439	-423	-337	-378	-341	-353	-444	-330	-249
ND	-609	-454	-529	-431	-657	-681	-663	-391	-454	-346	-474	-529	-488	-471	-445	-429	-346	-396	-398	-361	-439	-337	-241
MO	-129	-404	-324	-494	-157	-467	-197	-19	-179	5	-239	-437	-243	-235	-180	-149	44	-51	-119	-64	-263	-120	179
HF	-573	-537	-539	-400	-325	-422	-413	-327	-403	-302	-630	-491	-445	-427	-304	-391	-260	-327	-347	-308	-412	-338	-207
ER	-595	-442	-528	-404	-849	-439	-484	-377	-437	-355	-458	-511	-471	-455	-430	-415	-337	-374	-387	-352	-437	-377	-278
GA	-614	-318	-333	-376	-64	-449	-151	40	-136	66	-212	-318	-237	-207	-146	-135	110		-81	-22	-243	-95	266
HO	-230	-338	-163	-370	141	-213	67	366	46	382	-64	-190	-94	-30	56	61	446	274	129	203	-131	112	679
SM	-525	-450	-455	-409	-837	-437	-437	-302	-428	-318	-451	-407	-464	-448	-427	-406	-319	-360	-375	-338	-430	-365	-254
FE	-302	-310	-252	-348	115	-333	24	245	95	265	-80	-308	-110	-49	21	26	311	198	82	141	-145	70	472
GE	-290	96	-102	-78	634	-324	370	641	326	650	-60	-109	-96	267	384	350	700	556	409	469	-135	333	372
S	-120	103	227	-69	777	-35	557	1018	530	1016	385	-17	335	397	518	506	1105	846	593	680	193	547	1430
TB	-574	-591	-515	-490	-815	-427	-829	-355	-420	-332	-443	-498	-456	-440	-413	-399	-313	-363	-360	-333	-424	-359	-250
HO	-583	-554	-535	-407	-837	-437	-469	-373	-438	-350	-458	-508	-468	-452	-426	-412	-332	-370	-383	-348	-434	-373	-272
GD	-573	-549	-513	-498	-817	-420	-424	-352	-417	-329	-441	-497	-454	-438	-410	-396	-310	-350	-366	-330	-422	-357	-246
TA	-432	-409	-345	-488	-175	-375	-229	-81	-204	-58	-262	-348	-282	-258	-211	-200	-27	-103	-157	-109	-279	-156	40
K	-347	-328	-249	-411	-43	-292	-125	27	-110	87	-174	-269	-107	-172	-120	-112	80	-2	-68	-20	-210	-71	131
SN	-297	-347	-137	-366	43	-325	-17	186		204	-68	-203	-115	-84	-18	-12	249	136	46	97	-146	31	328
U	-470	-476	-637	-530	-335	-451	-304	-265	-337	-245	-367	-427	-381	-364	-334	-323	-226	-269	-273	-258	-363	-237	-163
ZN	-354	-333	-271	-420	-47	-395	-119	57	-97	79	-170	-270	-193	-166	-109	-100	117	22	-52		-207	-57	245
TH	-551	-479	-463	-478	-335	-406	-409	-336	-400	-315	-420	-479	-437	-421	-304	-341	-297	-316	-352	-318	-409	-314	-237
TC	-201	-193	-68	-302	233	-132	124	348	134	416	26	-113	-6	30	118	117	472	318	181	248	-63	153	673
W	-269	-351	-140	-351	41	-368		265	17	228	-64	-187	-69	-68			267	153	56	113	-132	46	415
NP	-445	-420	-345	-356	-249	-400	-285	-195	-276	-176	-312	-377	-327	-310	-274	-266	-156	-204	-238	-199	-317	-231	-48
PU	-440	-432	-340	-352	-249	-396	-282	-192	-272	-174	-306	-373	-354	-396	-273	-263	-154	-201	-232	-196	-314	-328	-46
BA	-433	-435	-378	-494	-347	-412	-309	-231	-330	-213	-332	-390	-345	-329	-300	-290	-196	-237		-229	-333	-257	-137
IN	-280	-348	-208	-450	17	-230	-74	123	-31	182	-107	-209	-130	-175	-84	-59	177	85	6	57	-156		229
SB	-140	-198	-132	-370	141	-130	72	200	94	276		-113	-28		67	70	313	212	119	170	-72	107	411
CO	-210	-179	-123	-408	145	-154	71	296	90	316	-10	-135	-39	-6	65	49	362	237	128	185	-85	112	523
AS	-190	-179	-96	-376	225	-130	117	376	138	393	23	-112	-7	27	108	111	446	301	172	236	-63	155	653
SE	-33	-91	61	-184	447	18	331	664	158	695	190	30	160	204	309	305	765	566	379	454	63	348	1017
RB	-207	-197	-151	-467	-9	-169	-44	49	-58	61	-87	-157		-94	-47	-43	80	30	-14	16	-124	-17	142
NI	-223	-208	-110	-318	185	-161	62	207	82	306	-13	-142	-47	-14	57	41	352	227	117	176	-91	104	512
TE	-100	-93	-10	-218	307	-84	149	445	219	459	103	-31	72	107	187	187	509	373	245	305	4	225	676
CU	-96	-73	-11	-168	187	-37	132	281	146	292	60	-27	48	72	126	128	320	243	167	207		156	414
CD	-181	-159	-129	-358	93	-133	32	178	75	191	-25	-119	-46	-22	29	33	220	143	73	115	-82	54	315
CS	-137	-140		-190	7	-119	-24	44	-10	52	-54	-111	-68	-54	-26	-23	65	30	-1	20	-88	-4	108
AE	-163	-120	-49	-383	333	-102	197	456	290	471	84	-85	57	90	178	175	525	376	237	302	-43	217	713
BI	-92	-93	-41	-182	192	-59	94	231	109	242	40	-51	-20	42	-42	-94	267	198	130	169	-28	171	351
RA	-14		78	-112	349	43	291	644	267	450	168	51	142	172	239	238	490	388	258	333	73	248	611
OS	-52	-43	10	-158	295		209	404	225	415	127	9	100	130	109	198	452	349	246	295	37	230	577
RU	-38	-26	69	-165	459	29	319	628	342	640	198	40	161	202	298	295	700	528	362	431	70	334	914
RH	33		50	-80	311	29	162	271	172	279	115	35	96	115	157	158	299	244	187	218	52	179	362
IR		7	48	-104	343	52	270	475	297	486	183	60	155	196	257	256	524	415	309	358	82	296	653
AU	108	112	144		415	154	351	529	346	536	271	157	246	273	318	315	568	476	378	421	168	350	673
PB	-101	-98	-49	-185	91	-67	41	195	40	158	10		-5	17	48	51	172	124	78	106	-35	72	229
AG	38	43	92	-37	252	72	203	310	213	317	154	76	137	156	107	197	336	292	226	255	90	216	397
TL	-41	-38	-9	-86	74	-20	91	104	54	109	26	-16	17	28	50	51	119	93	67	84	-3	64	149

Table 10 (cont.)

	MnO	Na_2O	MO_2	Bi_2O_3	MgO	Ti_3O_5	Ce_2O_3	CdO	K_2O	V_2O_2	SnO	Ta_2O_5	Ti_2O_3
BE	-475	-646	-665	-604	-551	-533	-619	-610	-477	-605	-539	-472	-415
LI	-496	-545	-409	-569	-523	-434	-470	-575	-418	-529	-498	-419	-424
AL	-461	-427	-415	-493	-476	-250	-466	-492	-415	-366	-423	-310	-142
MG	-466	-513	-472	-444	-507	-391	-542	-543	-464	-440	-474	-362	-297
B	-110	-13	-282	-334	-352	316	-336	-293	-140	-8	-227	-7	392
SC	-444	-441	-409	-431	-467	-230	-466	-460	-407	-361	-416	-312	-188
SI	-125	-73	-403	-234	-351	239	-335	-293	-150	-13	-230	-26	316
CA	-430	-413	-445	-597	-507	-419	-449	-560	-487	-646	-677	-409	-435
TI	-436	-235	-487	-607	-464		-410	-343	-264	-208	-323	-185	
P	21	113	-169	-250	-207	409	-247	-194	-31	118	-139	81	471
ZR	-314	-275	-396	-413	-609	-134	-416	-392	-365	-258	-336	-217	-72
V	-65	-8	-300	-247	-299	355	-215	-220	-63		-170		313
CR	19	89	-152	-231	-271	330	-227	-170	-27	99	-126	81	392
LA	-376	-394	-321	-630	-623	-241	-432	-414	-364	-330	-370	-251	-215
C	486	777	185	-4	-113	1374	6	102	492	726	151	561	1406
PR	-456	-317	-396	-459	-407	-226	-412	-397	-326	-209	-348	-260	-192
SR	-430	-279	-372	-331	-372	-199	-303	-371	-300	-265	-326	-233	-138
ND	-39	48	-180	-292	-206	294	-240	-204	-75	70	-157	68	308
NA	-63		-302	-249	-295	191	-243	-220	-92	5	-171	9	208
CE	-323	-233	-351	-394	-357	-234	-349	-370	-312	-280	-335	-247	-140
MO	-331	-345	-367	-403	-401	-214	-404	-304	-370	-200	-341	-254	-173
NB		49	-180	-214	-250	298	-215	-100	-37	65	-124	55	204
HF	-273	-230	-342	-367	-372	-191	-348	-340	-269	-228	-300	-201	-97
ER	-328	-230	-378	-304	-395	-220	-355	-374	-315	-246	-336	-254	-191
GA	51	133	-113	-193	-248	317	-109	-193	2	123	-97	107	380
HO	300	810	57	-93	-103	758	-65	-23	208	803	49	331	778
SM	-357	-299	-367	-384	-388	-191	-387	-364	-369	-264	-328	-234	-150
FE	324	357	27	-104	-179	527	-97	-30	151	295	24	241	564
GE	465	449	317	-94	-167	933	-86	-19	453	619	277	549	925
S	830	933	443	213	-56	1432	272	341	436	989	374	780	1454
TB	-303	-275	-362	-341	-384	-191	-387	-361	-365	-263	-320	-234	-151
HO	-310	-257	-378	-321	-342	-213	-363	-373	-310	-281	-332	-241	-174
GD	-390	-271	-359	-370	-362	-184	-346	-350	-362	-260	-318	-231	-146
TA	-59	-4	-176	-217	-270	197	-338	-196	-81		-152		195
K	35	89	-64	-173	-219	717	-144	-123		93	-60	81	288
SN	173	787	-7	-109	-172	454	-162	-64	110	242		207	493
U	-326	-134	-294	-324	-337	-111	-374	-290	-327	-180	-262	-144	-74
ZN	64	127	-86	-164	-218	305	-143	-115	20	127	-73	109	345
TH	-380	-241	-367	-344	-373	-191	-344	-388	-383	-251	-309	-225	-144
TC	487	849	107	-29	-118	728	-18	57	708	610	92	341	750
W	180	247		-44	-102	670	-83	-39	125	257	7	220	497
NP	-163	-133	-342	-241	-302	-37	-290	-251	-172	-174	-215	-111	-8
PU	-161	-139	-339	-274	-300	-37	-277	-249	-170	-192	-217	-109	-3
BA	-139	-173	-363	-394	-315	-91	-297	-272	-202	-163	-234	-108	-59
IN	120	147	-32	-121	-179	351	-115	-66	71	180	-27	-156	-384
SB	330	134	66	847	-118	634	-38	24	176	300	59	242	817
CO	357	320	65	-52	-128	578	-83	10	190	359	57	200	600
AS	330	633	101	-29	-113	855	-16	40	238	810	98	344	718
SE	477	731	370	91	-25	1052	165	190	435	674	230	561	1076
AB	54	44	-38	-100	-157	374	-46	-60	28	88	-34	61	198
NI	350	337	48	-59	-133	544	-49	1	183	331	51	242	809
TE	390	441	170	33	-61	714	43	114	300	467	188	401	767
CU	383	315	120	21	-39	837	30	63	310	310	109	279	471
CO	160	333	33	-59	-119	394	-88		123	218	50	104	343
CS	67	91	-30	-71	-112	131		-34	25	72	-18	67	-147
RE	394	423	139	-17	-96	758	-2	101	907	874	137	406	740
BI	719	749	89		-62	338	-5	50	173	261	-81	-237	-807
RH	104	871	220	93	-3	634	108	160	428	460	196	409	467
OS	467	445	182	59	-29	617	70	133	202	475	102	374	438
RU	441	643	764	99	-17	950	109	193	415	627	227	530	975
MO	354	335	150	48		337	75	119	219	202	139	270	804
IR	530	501	235	173	5	646	114	181	348	400	209	433	710
AU	486	417	311	143	80	690	192	250	412	536	291	488	718
PB	183	179	89	-17	-72	355	-12	24	112	177	46	140	274
AG	394	311	187	104	33	420	111	155	255	357	174	304	436
TL	104	127	50	7	-32	154	11	35	88	122	88	116	176

	BiO	Hg_2O	Al_2O_3	Ag_2O	Pb_3O_4	PbO	Ga_2O	TiO	TbO_2	Rb_2O	CeO_2	UO_3	Pb_2O
BE	-410	-292	-301	-476	-565	-403	-349	-403	-313	-342	-310	-434	-215
LI	-387	-280	-195	-549	-531	-379	-356	-337	-271	-316	-259	-382	-225
AL	-341	-256		-403	-470	-334	-244	-111	-177	-264	-159	-295	-192
MG	-376	-276	-185	-433	-510	-359	-344	-326	-259	-307	-247	-360	-223
B	-218	-186	785	-390	-317	-309	-114	326	133	-112	169	0	-113
SC	-341	-258	-62	-495	-462	-334	-206	-139	-132	-267	-174	-289	-194
SI	-220	-187	631	-384	-317	-212	-122	271	97	-118	137	-18	-115
CA	-384	-285	-258	-431	-510	-327	-357	-269	-293	-321	-290	-378	-214
TI	-270	-219	111	-436	-385	-275	-215		-75	-198	-55	-170	-153
P	-163	-156	787	-327	-240	-154	-15	400	202	-53	248	91	-96
ZR	-292	-232	49	-439	-392	-296	-234	-47	-113	-215	-93	-201	-163
V	-180	-166	535	-336	-256	-173	-97	378	139	-88	165	30	-121
CR	-153	-151	628	-309	-223	-145	-41	394	191	-49	229	62	-83
LA	-323	-257	-155	-448	-411	-317	-284	-183	-211	-263	-202	-276	-137
C	12	-59	2150	-167	-17	23	216	1090	662	165	754	529	0
PR	-307	-247	-118	-432	-392	-301	-265	-153	-134	-246	-175	-250	-194
SR	-201	-236	-100	-418	-375	-295	-243	-126	-157	-226	-141	-220	-177
ND	-162	-156	567	-322	-243	-165	-74	300	156	-77	133	60	-96
NA	-182	-147	420	-331	-255	-174	-86	222	98	-88	120	6	-121
CE	-208	-241	-93	-423	-381	-292	-253	-134	-142	-235		-234	-170
MO	-303	-244	-109	-426	-386	-237	-259	-146	-172	-241	-169	-243	-192
NB	-150	-148	461	-295	-212	-142	-17	268	147	-54	173	57	-90
HF	-273	-225	-22	-400	-352	-266	-219	-77	-123	-205	-109	-190	-152
ER	-300	-245	-124	-319	-379	-235	-259	-155	-185	-242	-175	-244	-184
GA	-132	-138	584	-282	-193	-124		343	193	-30	230	103	-72
HO	-39	-85	1105	-206	-96	-46	116	465	451	85	477	318	-38
SM	-201	-257	-86	-413	-370	-285	-204	-126	-141	-228	-151	-224	-176
FE	-48	-48	771	-217	-107	-54	86	502	339	62	372	244	-32
GE	131	22	1146	-212	-97	-45	312	824	615	262	663	535	-27
S	170	55	1923	-113	186	191	405	1228	851	332	935	742	97
TB	-289	-237	-40	-409	-366	-234	-243	-127		-227	-151	-223	-175
HO	-208	-243	-116	-417	-376	-292	-255	-149	-172	-239	-170	-239	-192
GD	-287	-235	-83	-408	-364	-231	-240	-123	-153	-225	-147	-219	-174
TA	-168	-159	310	-304	-230	-152	-78	175	72	-81	104	4	-77
K	-120	-130	415	-190	-170	-112	-18	263	155	-28	193	82	-60
SN	-68	-100	681	-213	-110	-60	58	442	295	38	323	202	-37
U	-247	-211	-12	-364	-313	-242	-193	-60	-102	-193	-90		-152
ZN	-114	-127	501	-255	-165	-107	-5	315	189	-16	220	106	-54
TH	-241	-253	-86	-498	-355	-276	-235	-122	-156	-221	-145	-214	-177
TC	-6	-64	1029	-160	-36	1	150	662	442	117	494	348	-1
W	-59	-94	693	-203	-99	-51	69	454	293	88	335	215	-32
NP	-212	-189	65	-330	-272	-206	-149	4	-65	-184	-31	-104	-130
PU	-211	-188	64	-327	-270	-205	-148	4	-65	-183	-31	-103	-130
BA	-230	-201	-2	-341	-299	-224	-175	-47	-87	-178	-75	-140	-144
IN	-80	-106	532	-216	-122	-72	33	354	200	17	260	154	-45
SB	-18	-67	673	-157	-48	-12	111	471	332	87	364	255	-9
CO	-25	-74	816	-171	-57	-17	115	542	366	88	438	281	-12
AS	-7	-64	964	-158	-36	1	145	631	435	113	473	334	-1
SE	82	-14	1427	-77	74	92	276	925	637	223	703	537	48
AB	-73	-97	264	-177	-102	-67	9	191	122		146	81	-46
NI	-29	-77	805	-175	-63	-21	110	534	359	83	491	274	-14
TE	38	-35	963	-106	21	46	196	466	471	159	519	368	24
CU	28	-33	578	-100	13	35	149	440	333	124	359	273	29
CO	-52	-73	492	-154	-59	-25	78	357	253	60	280	191	-17
CS	-52	-79	190	-111	-73	-48	14	145	103	6	115	68	-35
RE	25	-44	1038	-140	-20	35	149	495	489	151	531	391	17
BI		-43	502	-104	-15	17	122	383	238	100	312	233	0
RH	86		813	-51	80	94	233	612	464	197	501	398	55
OS	59	-17	790	-72	48	67	203	484	435	169	471	365	38
RU	86	-9	1263	-67	79	95	270	453	697	221	660	510	51
MO	66		474	-33	59	72	149	386	310	147	330	206	46
IR	93	3	868	-38	89	101	246	440	430	207	529	421	59
AU	-158	51	843	37	166	165	308	467	511	268	559	472	102
PB	-5	-49	338	-102			41	263	201	67	214	159	
AG	-66	22	507		94	102	201	416	343	177	361	300	67
TL	12	-24	205	-54	3	16	71	173	141	62	159	116	11

Table 10 (cont.)

	Li_2O	Y_2O_3	BaO	BeO	Sc_2O_3	Tl_2O	ZrO_2	Pr_6O_{11}	MgO_2	PuO_2	CaO	MgO	HfO_2	La_2O_3	UO_2	Pr_2O_3	Ho_2O_3	SrO	Nd_2O_3	Sm_2O_3	Gd_2O_3	Tb_2O_3	Ce_2O_3	Cs_2O	Pr_2O_3	PrO_2	Sr_2O	ThO_2
BE	-93	-266	-77		-143	-234	-330	-191	-160	-157	96	-43	-99	90	-16	13	28	-43	11	-10	-10	-5	-8	-241	38	-305	39	0
LI		-257	-43	93	-90	-239	-176	-169	-130	-128	134	26	-95	43	-89	45	53	-11	39	17	16	29	21	-228	62	-253	56	24
AL	155	-160	3	301	81	-204	-99	-69	-45	-84	356	155	22	145	17	115	116	64	109	46	83	89	93	-100	124	-153	100	44
HG	-76	-265	-58	63	-37	-234	-171	-169	-133	-129	106		-52	46	-54	92	40	-21	25	6	5	17	8	-221	48	-247	47	13
B	1129	159	303	1646	691	-134	813	247	147	156	408	908	711	548	241	605	369	364	390	354	344	347	390	-65	375	179	246	335
SC	66	-183	-19	143		-200	-87	-85	-85	-63	173	77	-9	113	-12	73	82	30	72	52	50	54	57	-195	90	-171	76	65
SI	963	64	193	1167	570	-130	344	232	136	136	701	756	276	607	316	346	336	326	353	321	311	315	342	-60	342	147	249	296
CA	-194	-272	-45	-90	-173	-234	-226	-191	-145	-163		-100	-112	5	-96	-34	-12	-75	-29	-36	-45	-38	-46	-236	-4	-275	9	-34
TI	297	-7	67	300	139	-177	97	1	-8	-8	364	226	77	183	60	153	149	111	196	126	123	127	134	-147	155	-61	125	122
P	1097	174	789	1734	706	-167	695	331	212	209	400	843	303	434	389	415	408	411	431	394	387	369	422	-46	413	252	302	364
ZA	178	-111	21	337	46	-189		-19	-33	-31	226	171	66	152	32	127	121	80	115	96	102	90	102	-162	127	-91	106	95
V	716	111	196	666	531	-117	339	236	156	159	413	635	290	392	324	367	332	327	346	310	310	317	317	-72	337	168	264	297
CR	815	199	171	544	543	-100	407	246	145	162	487	719	327	438	365	443	373	370	391	342	352	356	382	-69	378	227	267	336
LA	-617	-206	-78	-46	-112	-214	-153	-161	-150	-120	-6	-66	-65		-77	-33	-12	-54	-26	-78	-37	-32	-37	-205	-6	-192	4	-79
C	2687	686	661	3161	1727	-11	1215	803	946	532	1280	2089	797	921	423	873	779	658	648	738	771	760	848	100	780	754	642	716
FR	-46	-186	-66	-16	-76	-206	-122		-110	-106	28	-32	-62	32	-57		7	-35	-4	-16	-16	-11	-15	-192	13		20	-7
SA	-66	-139	-62	-16	-74	-183	-108	-81	-81	-80	-8	-47	-55	-8	-61	-20	41		-23	-37	-31	21	-31	-176	-9	-130		-26
NT	742	137	313	646	533	-109	349	260	176	176	635	600	392	411	285	377	350	344	366	334	329	332	357	-64	355	107	265	315
NA	[illegible]	8	176	656	406	-123	276	186	130	128	416	514	340	364	196	317	293	274	303	276	271	274	293	-71	294	132	230	261
CE	-21	-160	-67	8	-97	-146	-132	-89	-66	-79	86	-8	-96	17	-93	15	22	-19	11	-1	-1	2		-144	28	-155	11	4
ND	-98	-176	-65	-11	-73	-207	-114	-113	-103	-108	28	-25	-57	26	-53	8	11	-31		-12	-12	-7	-11	-188	17	-164	23	-5
SM	806	146	198	639	495	-107	318	233	163	161	439	566	273	370	326	349	319	309	331	337	300	302	322	-47	324	174	251	283
HF	55	-136	-9	49	8	-162	-66	-51	-50	-56	111	62		65	-5	62	65	27	57	33	42	44	46	-161	71	-104	45	46
ER	-62	-176	-67	-16	-90	-207	-137	-121	-118	-117	8	-48	-71	6	-65	-13	-5	-44	-17	-28	-28	-27	-28	-191		-172	9	-21
GA	756	170	337	850	551	-63	344	280	208	201	682	666	327	429	369	337	370	367	386	350	351	354	378	-30	374	233	267	336
EO	1336	376	495	1207	844	-49	737	531	377	377	1042	1158	550	658	448	622	468	497	605	570	554	558	600	50	571	480	420	523
SN	-17	-157	-44	10	-92	-146	-86	-68	-82	-91	46	-5	-43	18	-40	15	23	-17	12			4	1	-179	28	-148	32	5
FE	917	321	472	1017	719	-68	444	421	311	307	787	833	447	540	379	542	473	485	497	470	458	460	491	56	477	371	365	437
GE	1306	570	642	1289	1041	43	641	801	541	534	1096	1150	702	782	698	747	700	739	736	739	692	692	737	183	701	667	642	660
S	2301	770	687	2863	1474	70	1150	964	762	697	1455	1906	856	1042	771	1091	910	994	979	934	906	905	982	222	910	934	642	853
TH	-22	-157	-67	6	-96	-100	-48	-46	-93	-84	30	-12	-46	32	-83	11	18	-21	7	-4	-4		-2	-179	23	-142	28	1
HC	-63	-170	-72	-30	-47	-201	-135	-115	-109	-108	12	-80	-65	12	-60	-7		-41	-11	-23	-22	-18	-22	-198	5	-167	13	-15
GC	-18	-156	-43	10	-90	-107	-43	-62	-90	-84	44	-5	-42	37	-40	15	22	-17	12			4	1	-177	28	-144	31	5
TA	418	67	168	477	317	-118	317	160	111	168	606	389	371	291	168	244	251	233	256	236	231	234	247	-67	256	107	204	225
K	-35	160	302	377	407	-68	504	239	172	170	687	464	248	354	227	359	310	309	320	290	293	298	312	-29	315	185	250	283
SI	416	260	406	608	691	-66	497	378	270	277	714	740	472	605	437	445	434	437	454	428	418	419	387	19	437	326	337	400
C	45		-5	30	12	-171	-42	-60	-47	-84	96	35	3	77		67	60	27	53	30	40	47	43	-147	65	-87	41	43
ZL	621	170	728	185	697	-88	341	273	169	194	564	573	308	399	358	379	348	342	361	338	330	332	353	-20	352	222	275	318
TL	-27	-157	-46	6	-45	-167	-49	-93	-31	-90	38	-13	-36	29	-43	2	15	-22	5	-6	-5	-1	-4	-176	21	-103	26	
TI	1216	409	411	1366	936	-27	735	541	300	361	997	1079	558	696	462	627	573	601	608	575	561	561	503	77	576	406	432	532
N	477	271	446	616	692	-61	464	389	264	287	723	756	413	504	356	474	442	449	463	437	427	428	457	26	446	338	346	405
NP	112	-48	38	146	95	-160	94	16		0	164	131	56	130	47	117	109	31	105	92	90	97	96	-117	114	-20	100	91
PU	127	-47	37	197	83	-160	93	16	u		163	129	56	129	46	133	108	30	104	91	89	92	95	-116	113	-28	99	90
BA	6	-67		77	14	-162	-71	-30	-38	-37	95	58	9	78	5	67	62	31	55	40	43	47	47	-137	67	-73	62	45
IL	641	209	367	763	512	-88	347	304	231	228	486	596	338	625	287	394	373	371	387	365	357	350	380	4	377	262	296	344
SB	742	320	432	863	819	-76	415	407	312	309	702	727	430	511	367	493	455	463	474	451	441	449	469	55	458	366	361	424
CO	496	354	458	1037	759	-94	436	460	360	334	825	872	478	549	401	559	501	514	526	494	487	468	521	54	504	411	346	464
AS	1131	387	476	1343	846	-91	440	520	349	370	641	1010	439	614	486	601	456	579	587	554	543	547	493	71	558	474	432	515
SE	1646	560	469	1936	1271	30	848	742	504	537	1278	1449	742	840	411	857	735	799	785	717	727	724	784	148	736	705	545	646
AE	716	170	178	247	347	-67	710	180	164	143	321	307	275	243	184	204	239	224	241	228	225	227	235	-6	242	148	207	221
NI	1069	910	493	1046	750	-44	467	488	336	330	616	802	471	543	395	532	495	509	520	497	481	462	415	51	498	407	392	457
TE	1169	536	495	1349	896	-	716	559	428	418	663	1008	473	640	483	627	585	610	616	597	573	570	412	107	587	527	451	547
CD	1093	311	337	688	941	-	671	393	317	318	611	821	412	478	363	457	434	434	449	430	423	424	484	88	437	361	358	409
CO	1173	230	372	616	880	-34	945	319	241	260	440	545	393	415	390	377	373	371	385	366	356	361	379	38	376	282	356	340
CS	346	77	137	261	199	-66	142	140	117	116	334	221	151	205	147	192	188	174	188	170	177	170	184		191	114	170	175
RE	1267	440	440	1333	991	-1	744	574	479	627	1001	1003	598	690	491	647	599	628	633	602	587	580	430	99	601	537	454	559
BI	460	370	472	608	491	-7	413	346	281	278	463	548	357	410	324	437	391	391	463	356	379	381	356	71	394	314	336	366
RH	468	436	493	671	773	30	492	535	420	427	818	832	547	619	476	534	559	578	564	540	550	550	580	140	562	503	489	529
OS	891	464	412	647	790	30	835	507	460	396	799	833	422	507	451	571	537	554	561	537	526	527	557	119	540	473	439	506
RU	1666	551	575	1584	1196	37	916	698	522	515	1178	1294	702	794	585	759	700	744	744	729	691	691	742	149	701	662	528	655
HG	1073	266	315	541	867	37	856	347	302	300	407	507	372	423	337	467	392	392	401	337	342	364	397	112	394	332	337	373
IR	1071	657	464	1039	822	61	681	563	446	441	866	907	474	647	497	621	584	604	611	594	575	576	407	147	556	531	466	552
AG	923	561	401	875	808	64	703	562	440	602	848	875	650	663	530	610	407	627	631	610	599	590	478	199	609	564	497	575
PB	479	191	326	403	316	-16	245	246	208	204	377	369	256	317	281	391	292	285	297	295	281	262	292	49	295	210	254	275
AC	496	326	341	536	639	51	640	366	330	327	431	533	400	440	364	432	417	415	427	413	408	409	423	137	419	362	340	398
TL	1239	130	172	1239	209		145	169	149	148	236	220	192	218	171	208	201	193	202	195	194	198	198	49	203	151	186	192

C. Nitrate and Nitrite Reactions

The interactions of 18 nitrates and 8 nitrites with metals were examined, and 1226 reactions resulted. The groups of reactions embodying the nitrates and nitrites are highly energetic. In general, the nitrates are more energetic than the nitrites.

The data for a few of the more energetic reactions are shown in Table 11. These data were abstracted from the series of reactions of elements with lead nitrate listed on the computer data sheets. Reactions with lead nitrate can produce several oxides. For aluminum, boron, beryllium, calcium, and cesium, the most energetic reaction produces Pb_2O. For barium, bismuth, carbon, and cadmium, the most energetic reaction produces PbO. The reactions producing Pb_2O are generally more energetic.

Table 12 lists the 199 most energetic nitrate and nitrite reactions. Beryllium, uranium, hafnium, aluminum, zirconium, thorium, boron, titanium, tantalum, neodymium, lanthanum, scandium, praseodymium, cerium, magnesium, silicon, vanadium, chromium, niobium, gallium, and calcium are the best reducing metals, in that order. Lithium nitrate, lead nitrate, calcium nitrate, strontium nitrate, silver nitrate, sodium nitrate, barium nitrate, potassium nitrate, rubidium nitrate, barium nitrite, silver nitrite, sodium nitrite, and cesium nitrate are the best oxidizing agents, in that order. These relationships are depicted graphically in Figures 8, 9, and 10.

The periodicity of the data is apparent in Figure 8. These curves are similar to those depicting the behavior of oxides with metals, and the same rules seem to be applicable. The "rule of nine" that was observed in the oxide reactions is still valid: the minima in the curve, corresponding to maximum thermal outputs, occur at every ninth atomic number starting with beryllium, aluminum, titanium, gallium, zirconium, indium (no data), lanthanum, and hafnium.

The dotted lines connect the members of a periodic group with five or more members. Thus, the members of Groups IA (lithium, sodium, potassium, rubidium, and cesium) and IIA (beryllium, magnesium, calcium, strontium, and barium) are connected. The energy of the reaction decreases with increasing atomic number of the members of a group. This is generally true for the other "long" groups (IIIA and VIA), except for anomalies evident at aluminum and carbon.

These anomalies are related to the volumetric enthalpy, which is highly dependent upon the heats of formation of the products and reactants, on the volume of the reactants, and on the coefficients of the terms in the balanced equation. Aluminum and boron have the same stoichiometric coefficients, and

Table 11

DATA ON REACTIONS OF VARIOUS METALS WITH LEAD NITRATE

	22 Al	+ 6 $Pb(NO_3)_2$	= 3 Pb_2O	+ 11 Al_2O_3	+ 6 N_2
Heat of formation		-107.35	-51.20	-399.09	
Molecular weight	26.98	331.23	430.42	101.94	28.02
Density	2.70	4.53	8.34	3.97	
Melting point, °C	660.00	470.00		2015.00	-209.86
Boiling point, °C	2327.00			3500.00	-195.80
Heat of reaction, kcal	-3899.49				
Reactants' density	3.92				
Gravimetric enthalpy, cal/g	-1501.88				
Volumetric enthalpy, cal/cc	-5922.77				

	22 B	+ 6 $Pb(NO_3)_2$	= 3 Pb_2O	+ 11 B_2O_3	+ 6 N_2
Heat of formation		-107.35	-51.20	-302.00	
Molecular weight	10.82	331.23	430.42	69.64	28.02
Density	2.37	4.53	8.34	1.84	
Melting point, °C	2040.00	470.00		450.00	-209.86
Boiling point, °C	2550.00			1500.00	-195.00
Heat of reaction, kcal	-2831.50				
Reactants' density	4.13				
Gravimetric enthalpy, cal/g	-1272.34				
Volumetric enthalpy, cal/cc	-5251.75				

	5 Ba	+ $Pb(NO_3)_2$	= PbO	+ 5 BaO	+ N_2
Heat of formation		-107.35	-52.40	-133.40	
Molecular weight	-137.36	331.23	223.21	153.36	28.02
Density	3.50	4.53	8.00	5.72	
Melting point, °C	704.00	470.00		1923.00	-209.86
Boiling point, °C	1638.00			2000.00	-195.80
Heat of reaction, kcal	-612.05				
Reactants' density	3.78				
Gravimetric enthalpy, cal/g	-601.21				
Volumetric enthalpy, cal/cc	-2272.34				

Table 11 (cont.)

	11 Be	+ 2 $Pb(NO_3)_2$ =	Pb_2O +	11 BeO +	2 N_2
Heat of formation		-107.35	-51.20	-146.00	
Molecular weight	9.01	331.23	430.42	25.01	28.02
Density	1.85	4.53	8.34	3.01	
Melting point, °C	1283.00	470.00		2530.00	-209.86
Boiling point, °C	2970.00			3900.00	-195.80
Heat of reaction, kcal	-1442.50				
Reactants' density	3.81				
Gravimetric enthalpy, cal/g	-1894.03				
Volumetric enthalpy, cal/cc	-7218.66				

	10 Bi	+ 3 $Pb(NO_3)_2$ =	3 PbO +	5 Bi_2O_3 +	3 N_2
Heat of formation		-107.35	-52.40	-137.90	
Molecular weight	208.99	331.23	223.21	466.00	28.02
Density	9.80	4.53	8.00	8.90	
Melting point, °C	271.00	470.00		820.00	-209.86
Boiling point, °C	1420.00			1890.00	-195.80
Heat of reaction, kcal	-524.65				
Reactants' density	7.13				
Gravimetric enthalpy, cal/g	-170.14				
Volumetric enthalpy, cal/cc	-1212.75				

	5 C	+ 2 $Pb(NO_3)_2$ =	2 PbO +	5 CO_2 +	2 N_2
Heat of formation		-107.35	-52.40	-94.05	
Molecular weight	12.01	331.23	223.21	44.01	28.02
Density	2.25	4.53	8.00	1.98	
Melting point, °C	25.00	470.00		-56.20	-209.86
Boiling point, °C	4347.00			-78.50	-195.80
Heat of reaction, kcal	-360.35				
Reactants' density	4.18				
Gravimetric enthalpy, cal/g	-498.74				
Volumetric enthalply, cal/cc	-2083.80				

Table 11 (cont.)

	11 Ca	+ 2 $Pb(NO_3)_2$	= Pb_2O	+ 11 CaO	+ 2 N_2
Heat of formation		-107.35	-51.20	-151.90	
Molecular weight	40.08	331.23	430.42	56.08	28.02
Density	1.55	4.53	8.34	3.35	
Melting point, °C	850.00	470.00		2580.00	-209.86
Boiling point, °C	1240.00			2850.00	-195.80
Heat of reaction, kcal	-1507.40				
Reactants' density	2.56				
Gravimetric enthalpy, cal/g	-1366.22				
Volumetric enthalpy, cal/cc	-3500.07				

	5 Cd	+ $Pb(NO_3)_2$	= PbO	+ 5 CdO	+ N_2
Heat of formation		-107.35	-52.40	-60.86	
Molecular weight	112.41	331.23	223.21	128.41	28.02
Density	8.64	4.53	8.00	8.15	
Melting point, °C	320.90	470.00		900.00	-209.86
Boiling point, °C	767.00				-195.80
Heat of reaction, kcal	-249.35				
Reactants' density	6.47				
Gravimetric enthalpy, cal/g	-279.14				
Volumetric enthalpy, cal/cc	-1804.64				

	22 Ce	+ 6 $Pb(NO_3)_2$	= 3 Pb_2O	+ 11 Ce_2O_3	+ 6 N_2
Heat of formation		-107.35	-51.20	-435.00	
Molecular weight	140.13	331.23	430.42	328.26	28.02
Density	6.70	4.53	8.34	6.90	
Melting point, °C	775.00	470.00		1692.00	-209.86
Boiling point, °C	2900.00				-195.80
Heat of reaction, kcal	-4294.50				
Reactants' density	5.64				
Gravimetric enthalpy, cal/g	-847.00				
Volumetric enthalpy, cal/cc	-4777.81				

Table 12

MOST ENERGETIC NITRATE AND NITRITE REACTIONS WITH METALS, IN TERMS OF VOLUMETRIC ENTHALPY

Reaction	Enthalpy, cal/cc
$5\,Be + 2\,Li(NO_3) = Li_2O + 5\,BeO + N_2$	-7798
$11\,Be + 2\,Pb(NO_3)_2 = Pb_2O + 11\,BeO + 2\,N_2$	-7218
$5\,Be + Ca(NO_3)_2 = CaO + 5\,BeO + N_2$	-7006
$5\,Be + Sr(NO_3)_2 = SrO + 5\,BeO + N_2$	-6697
$5\,Be + 2\,Ag(NO_3) = Ag_2O + 5\,BeO + N_2$	-6623
$5\,U + 4\,Li(NO_3) = 2\,Li_2O + 5\,UO_2 + 2\,N_2$	-6537
$5\,Hf + 4\,Li(NO_3) = 2\,Li_2O + 5\,HfO_2 + 2\,N_2$	-6454
$10\,Al + 6\,Li(NO_3) = 3\,Li_2O + 5\,Al_2O_3 + 3\,N_2$	-6324
$11\,U + 4\,Pb(NO_3)_2 = 2\,Pb_2O + 11\,UO_2 + 4\,N_2$	-6110
$5\,Be + 2\,Na(NO_3) = Na_2O + 5\,BeO + N_2$	-6090
$11\,Hf + 4\,Pb(NO_3)_2 = 2\,Pb_2O + 11\,HfO_2 + 4\,N_2$	-6042
$5\,Be + Ba(NO_3)_2 = BaO + 5\,BeO + N_2$	-5963
$5\,Zr + 4\,Li(NO_3) = 2\,Li_2O + 5\,ZrO_2 + 2\,N_2$	-5956
$5\,U + 2\,Ca(NO_3)_2 = 2\,CaO + 5\,UO_2 + 2\,N_2$	-5948
$22\,Al + 6\,Pb(NO_3)_2 = 3\,Pb_2O + 11\,Al_2O_3 + 6\,N_2$	-5922
$5\,Hf + 2\,Ca(NO_3)_2 = 2\,CaO + 5\,HfO_2 + 2\,N_2$	-5884
$5\,Th + 4\,Li(NO_3) = 2\,Li_2O + 5\,ThO_2 + 2\,N_2$	-5849
$10\,Al + 3\,Ca(NO_3)_2 = 3\,CaO + 5\,Al_2O_3 + 3\,N_2$	-5767
$10\,B + 6\,Li(NO_3) = 3\,Li_2O + 5\,B_2O_3 + 3\,N_2$	-5674
$5\,U + 2\,Sr(NO_3)_2 = 2\,SrO + 5\,UO_2 + 2\,N_2$	-5674
$5\,U + 4\,Ag(NO_3) = 2\,Ag_2O + 5\,UO_2 + 2\,N_2$	-5672
$5\,Hf + 4\,Ag(NO_3) = 2\,Ag_2O + 5\,HfO_2 + 2\,N_2$	-5618
$5\,Hf + 2\,Sr(NO_3)_2 = 2\,SrO + 5\,HfO_2 + 2\,N_2$	-5616
$10\,Ti + 6\,Li(NO_3) = 3\,Li_2O + 5\,Ti_2O_3 + 3\,N_2$	-5603
$11\,Zr + 4\,Pb(NO_3)_2 = 2\,Pb_2O + 11\,ZrO_2 + 4\,N_2$	-5594
$11\,Th + 4\,Pb(NO_3)_2 = 2\,Pb_2O + 11\,ThO_2 + 4\,N_2$	-5544
$10\,Al + 6\,Ag(NO_3) = 3\,Ag_2O + 5\,Al_2O_3 + 3\,N_2$	-5510
$10\,Al + 3\,Sr(NO_3)_2 = 3\,SrO + 5\,Al_2O_3 + 3\,N_2$	-5500
$5\,Zr + 2\,Ca(NO_3)_2 = 2\,CaO + 5\,ZrO_2 + 2\,N_2$	-5452

Table 12 (cont.)

Reaction	Enthalpy, cal/cc
5 Th + 2 $Ca(NO_3)_2$ = 2 CaO + 5 ThO_2 + 2 N_2	-5422
22 Ti + 6 $Pb(NO_3)_2$ = 3 Pb_2O + 11 Ti_2O_3 + 6 N_2	-5270
22 B + 6 $Pb(NO_3)_2$ = 3 Pb_2O + 11 B_2O_3 + 6 N_2	-5251
5 Th + 4 $Ag(NO_3)$ = 2 Ag_2O + 5 ThO_2 + 2 N_2	-5224
5 Zr + 4 $Ag(NO_3)$ = 2 Ag_2O + 5 ZrO_2 + 2 N_2	-5223
5 Th + 2 $Sr(NO_3)_2$ = 2 SrO + 5 ThO_2 + 2 N_2	-5199
5 Zr + 2 $Sr(NO_3)_2$ = 2 SrO + 5 ZrO_2 + 2 N_2	-5195
5 Ta + 2 $Li(NO_3)$ = Li_2O + Ta_2O_5 + N_2	-5163
5 U + 4 $Na(NO_3)$ = 2 Na_2O + 5 UO_2 + 2 N_2	-5151
10 Ti + 3 $Ca(NO_3)_2$ = 3 CaO + 5 Ti_2O_3 + 3 N_2	-5137
5 Hf + 4 $Na(NO_3)$ = 2 Na_2O + 5 HfO_2 + 2 N_2	-5104
10 B + 3 $Ca(NO_3)_2$ = 3 CaO + 5 B_2O_3 + 3 N_2	-5088
10 Nd + 6 $Li(NO_3)$ = 3 Li_2O + 5 Nd_2O_3 + 3 N_2	-5080
5 U + 2 $Ba(NO_3)_2$ = 2 BaO + 5 UO_2 + 2 N_2	-5078
10 La + 6 $Li(NO_3)$ = 3 Li_2O + 5 La_2O_3 + 3 N_2	-5067
3 Be + 2 $Ag(NO_2)$ = Ag_2O + 3 BeO + N_2	-5064
10 Sc + 6 $Li(NO_3)$ = 3 Li_2O + 5 Sc_2O_3 + 3 N_2	-5062
5 Hf + 2 $Ba(NO_3)_2$ = 2 BaO + 5 HfO_2 + 2 N_2	-5034
10 Pr + 6 $Li(NO_3)$ = 3 Li_2O + 5 Pr_2O_3 + 3 N_2	-5012
10 Al + 6 $Na(NO_3)$ = 3 Na_2O + 5 Al_2O_3 + 3 N_2	-4991
10 Ce + 6 $Li(NO_3)$ = 3 Li_2O + 5 Ce_2O_3 + 3 N_2	-4988
5 Mg + 2 $Li(NO_3)$ = Li_2O + 5 MgO + N_2	-4936
10 Ti + 6 $Ag(NO_3)$ = 3 Ag_2O + 5 Ti_2O_3 + 3 N_2	-4932
10 Al + 3 $Ba(NO_3)_2$ = 3 BaO + 5 Al_2O_3 + 3 N_2	-4927
10 Ti + 3 $Sr(NO_3)_2$ = 3 SrO + 5 Ti_2O_3 + 3 N_2	-4884
5 Si + 4 $Li(NO_3)$ = 2 Li_2O + 5 SiO_2 + 2 N_2	-4877
22 Nd + 6 $Pb(NO_3)_2$ = 3 Pb_2O + 11 Nd_2O_3 + 6 N_2	-4864
22 La + 6 $Pb(NO_3)_2$ = 3 Pb_2O + 11 La_2O_3 + 6 N_2	-4860
10 B + 6 $Ag(NO_3)$ = 3 Ag_2O + 5 B_2O_3 + 3 N_2	-4842
5 Be + 2 $K(NO_3)$ = K_2O + 5 BeO + N_2	-4831

Table 12 (cont.)

Reaction	Enthalpy, cal/cc
$22\ Sc + 6\ Pb(NO_3)_2 = 3\ Pb_2O + 11\ Sc_2O_3 + 6\ N_2$	-4830
$5\ Be + 2\ Rb(NO_3) = Rb_2O + 5\ BeO + N_2$	-4821
$22\ Ta + 10\ Pb(NO_3)_2 = 5\ Pb_2O + 11\ Ta_2O_5 + 10\ N_2$	-4821
$22\ Pr + 6\ Pb(NO_3)_2 = 3\ Pb_2O + 11\ Pr_2O_3 + 6\ N_2$	-4804
$22\ Ce + 6\ Pb(NO_3)_2 = 3\ Pb_2O + 11\ Ce_2O_3 + 6\ N_2$	-4777
$10\ B + 3\ Sr(NO_3)_2 = 5\ SrO + 5\ B_2O_3 + 3\ N_2$	-4775
$5\ Th + 4\ Na(NO_3) = 2\ Na_2O + 5\ ThO_2 + 2\ N_2$	-4774
$10\ Nd + 3\ Ca(NO_3)_2 = 3\ CaO + 5\ Nd_2O_3 + 3\ N_2$	-4773
$10\ La + 3\ Ca(NO_3)_2 = 3\ CaO + 5\ La_2O_3 + 3\ N_2$	-4772
$10\ Sc + 3\ Ca(NO_3)_2 = 3\ CaO + 5\ Sc_2O_3 + 3\ N_2$	-4733
$11\ Mg + 2\ Pb(NO_3)_2 = Pb_2O + 11\ MgO + 2\ N_2$	-4729
$5\ Th + 2\ Ba(NO_3)_2 = 2\ BaO + 5\ ThO_2 + 2\ N_2$	-4728
$10\ Pr + 3\ Ca(NO_3)_2 = 3\ CaO + 5\ Pr_2O_3 + 3\ N_2$	-4716
$5\ Zr + 4\ Na(NO_3) = 2\ Na_2O + 5\ ZrO_2 + 2\ N_2$	-4708
$2\ Nb + 2\ Li(NO_3) = Li_2O + Nb_2O_5 + N_2$	-4707
$10\ Ce + 3\ Ca(NO_3)_2 = 3\ CaO + 5\ Ce_2O_3 + 3\ N_2$	-4688
$2\ Ta + Ca(NO_3)_2 = CaO + Ta_2O_5 + N_2$	-4683
$3\ Be + 2\ Na(NO_2) = Na_2O + 3\ BeO + N_2$	-4670
$5\ Zr + 2\ Ba(NO_3)_2 = 2\ BaO + 5\ ZrO_2 + 2\ N_2$	-4658
$5\ Mg + Ca(NO_3)_2 = CaO + 5\ MgO + N_2$	-4641
$10\ La + 6\ Ag(NO_3) = 3\ Ag_2O + 5\ La_2O_3 + 3\ N_2$	-4640
$3\ Be + Ba(NO_2)_2 = BaO + 3\ BeO + N_2$	-4640
$10\ La + 3\ Sr(NO_3)_2 = 3\ SrO + 5\ La_2O_3 + 3\ N_2$	-4591
$10\ Sc + 6\ Ag(NO_3) = 3\ Ag_2O + 5\ Sc_2O_3 + 3\ N_2$	-4589
$11\ Si + 4\ Pb(NO_3)_2 = 2\ Pb_2O + 11\ SiO_2 + 4\ N_2$	-4587
$10\ Nd + 3\ Sr(NO_3)_2 = 3\ SrO + 5\ Nd_2O_3 + 3\ N_2$	-4584
$10\ Pr + 6\ Ag(NO_3) = 3\ Ag_2O + 5\ Pr_2O_3 + 3\ N_2$	-4584
$10\ V + 6\ Li(NO_3) = 3\ Li_2O + 5\ V_2O_3 + 3\ N_2$	-4571
$10\ Ce + 6\ Ag(NO_3) = 3\ Ag_2O + 5\ Ce_2O_3 + 3\ N_2$	-4556
$10\ Pr + 3\ Sr(NO_3)_2 = 3\ SrO + 5\ Pr_2O_3 + 3\ N_2$	-4531

Table 12 (cont.)

Reaction	Enthalpy, cal/cc
$10\ Sc + 3\ Sr(NO_3)_2 = 3SrO + 5\ Sc_2O_3 + 3\ N_2$	-4531
$5\ Mg + 2\ Ag(NO_3) = Ag_2O + 5\ MgO + N_2$	-4512
$10\ Ce + 3\ Sr(NO_3)_2 = 3\ SrO + 5\ Ce_2O_3 + 3\ N_2$	-4501
$2\ Ta + 2\ Ag(NO_3) = Ag_2O + Ta_2O_5 + N_2$	-4489
$5\ Si + 2\ Ca(NO_3)_2 = 2\ CaO + 5\ SiO_2 + 2\ N_2$	-4467
$5\ Mg + Sr(NO_3)_2 = SrO + 5\ MgO + N_2$	-4454
$3\ U + 4\ Ag(NO_2) = 2\ Ag_2O + 3\ UO_2 + 2\ N_2$	-4433
$10\ Ti + 6\ Na(NO_3) = 3\ Na_2O + 5\ Ti_2O_3 + 3\ N_2$	-4409
$22\ Nb + 10\ Pb(NO_3)_2 = 5\ Pb_2O + 11\ Nb_2O_5 + 10\ N_2$	-4408
$3\ Hf + 4\ Ag(NO_2) = 2\ Ag_2O + 3\ HfO_2 + 2\ N_2$	-4407
$10\ Cr + 6\ Li(NO_3) =$ [illegible]$_2O + 5\ Cr_2O_3 + 3\ N_2$	-4405
$2\ Ta + Sr(NO_3)_2 = SrO + Ta_2O_5 + N_2$	-4399
$5\ Be + 2\ Cs(NO_3) = Cs_2O + 5\ BeO + N_2$	-4377
$10\ Ti + 3\ Ba(NO_3)_2 = 3\ BaO + 5\ Ti_2O_3 + 3\ N_2$	-4373
$2\ Al + 2\ Ag(NO_2) = Ag_2O + Al_2O_3 + N_2$	-4323
$22\ V + 6\ Pb(NO_3)_2 = 3\ Pb_2O + 11\ V_2O_3 + 6\ N_2$	-4306
$5\ Si + 4\ Ag(NO_3) = 2\ Ag_2O + 5\ SiO_2 + 2\ N_2$	-4303
$2\ Nb + Ca(NO_3)_2 = CaO + Nb_2O_3 + N_2$	-4285
$10\ La + 6\ Na(NO_3) = 3\ Na_2O + 5\ La_2O_3 + 3\ N_2$	-4250
$3\ Th + 4\ Ag(NO_2) = 2\ Ag_2O + 3\ ThO_2 + 2\ N_2$	-4232
$10\ Nd + 6\ Na(NO_3) = 3\ Na_2O + 5\ Nd_2O_3 + 3\ N_2$	-4230
$10\ La + 3\ Ba(NO_3)_2 = 3\ BaO + 5\ La_2O_3 + 3\ N_2$	-4229
$10\ Nd + 3\ Ba(NO_3)_2 = 3\ BaO + 5\ Nd_2O_3 + 3\ N_2$	-4209
$5\ Si + 2\ Sr(NO_3)_2 = 2\ SrO + 5\ SiO_2 + 2\ N_2$	-4207
$10\ B + 6\ Na(NO_3) = 3\ Na_2O + 5\ B_2O_3 + 3\ N_2$	-4199
$10\ V + 3\ Ca(NO_3)_2 = 3\ CaO + 5\ V_2O_3 + 3\ N_2$	-4195
$10\ Pr + 6\ Na(NO_3) = 3\ Na_2O + 5\ Pr_2O_4 + 3\ N_2$	-4185
$10\ B + 3\ Ba(NO_3)_2 = 3\ BaO + 5\ B_2O_3 + 3\ N_2$	-4168
$10\ Pr + 3\ Ba(NO_3)_2 = 3\ BaO + 5\ Pr_2O_3 + 3\ N_2$	-4166
$10\ Sc + 6\ Na(NO_3) = 3\ Na_2O + 5\ Sc_2O_3 + 3\ N_2$	-4153

Table 12 (cont.)

Reaction	Enthalpy, cal/cc
10 Ce + 6 $Na(NO_3)$ = 3 Na_2O + 5 Ce_2O_3 + 3 N_2	-4149
22 Cr + 6 $Pb(NO_3)_2$ = 3 Pb_2O + 11 Cr_2O_3 + 6 N_2	-4143
10 Sc + 3 $Ba(NO_3)_2$ = 3 BaO + 5 Sc_2O_3 + 3 N_2	-4143
10 Ce + 3 $Ba(NO_3)_2$ = 3 BaO + 5 Ce_2O_3 + 3 N_2	-4131
3 Zr + 4 $Ag(NO_2)$ = 2 Ag_2O + 3 ZrO_2 + 2 N_2	-4126
2 Nb + 2 $Ag(NO_3)$ = Ag_2O + Nb_2O_3 + N_2	-4124
5 U + 4 $K(NO_3)$ = 2 K_2O + 5 UO_2 + 2 N_2	-4118
5 Mg + 2 $Na(NO_3)$ = Na_2O + 5 MgO + N_2	-4104
5 U + 4 $Rb(NO_3)$ = 2 Rb_2O + 5 UO_2 + 2 N_2	-4103
5 Hf + 4 $K(NO_3)$ = 2 K_2O + 5 HfO_2 + 2 N_2	-4092
5 Mg + $Ba(NO_3)_2$ = BaO + 5 MgO + N_2	-4088
5 Hf + 4 $Rb(NO_3)$ = 2 Rb_2O + 5 HfO_2 + 2 N_2	-4077
10 V + 6 $Ag(NO_3)$ = 3 Ag_2O + 5 V_2O_3 + 3 N_2	-4051
3 U + 2 $Ba(NO_2)_2$ = 2 BaO + 3 UO_2 + 2 N_2	-4043
10 Cr + 3 $Ca(NO_3)_2$ = 3 CaO + 5 Cr_2O_3 + 3 N_2	-4031
3 Hf + 2 $Ba(NO_2)_2$ = 2 BaO + 3 HfO_2 + 2 N_2	-4022
3 U + 4 $Na(NO_2)$ = 2 Na_2O + 3 UO_2 + 2 N_2	-4018
2 Nb + $Sr(NO_3)_2$ = SrO + Nb_2O_5 + N_2	-4006
3 Hf + 4 $Na(NO_2)$ = 2 Na_2O + 3 HfO_2 + 2 N_2	-3996
10 Al + 6 $K(NO_3)$ = 3 K_2O + 5 Al_2O_3 + 3 N_2	-3995
10 Al + 6 $Rb(NO_3)$ = 3 Rb_2O + 5 Al_2O_3 + 3 N_2	-3980
2 Al + $Ba(NO_2)_2$ = BaO + Al_2O_3 + N_2	-3940
10 V + 3 $Sr(NO_3)_2$ = 3 SrO + 5 V_2O_3 + 3 N_2	-3936
5 Th + 4 $K(NO_3)$ = 2 K_2O + 5 ThO_2 + 2 N_2	-3933
5 Th + 4 $Rb(NO_3)$ = 2 Rb_2O + 5 ThO_2 + 2 N_2	-3920
2 Al + 2 $Na(NO_2)$ = Na_2O + Al_2O_3 + N_2	-3906
2 Ti + 2 $Ag(NO_2)$ = Ag_2O + Ti_2O_3 + N_2	-3905
10 Cr + 6 $Ag(NO_3)$ = 3 Ag_2O + 5 Cr_2O_3 + 3 N_2	-3895
3 Th + 2 $Ba(NO_2)_2$ = 2 BaO + 3 ThO_2 + 2 N_2	-3892
2 La + 2 $Ag(NO_2)$ = Ag_2O + La_2O_3 + N_2	-3885

Table 12 (cont.)

Reaction	Enthalpy, cal/cc
$2\ Ta + 2\ Na(NO_3) = Na_2O + Ta_2O_5 + N_2$	-3873
$5\ Mn + 2\ Li(NO_3) = Li_2O + 5\ MnO + N_2$	-3869
$2\ Ta + Ba(NO_3)_2 = BaO + Ta_2O_5 + N_2$	-3866
$3\ Th + 4\ Na(NO_2) = 2\ Na_2O + 3\ ThO_2 + 2\ N_2$	-3859
$2\ Nd + 2\ Ag(NO_2) = Ag_2O + Nd_2O_3 + N_2$	-3858
$2\ Pr + 2\ Ag(NO_2) = Ag_2O + Pr_2O_3 + N_2$	-3828
$2\ Ce + 2\ Ag(NO_2) = Ag_2O + Ce_2O_3 + N_2$	-3793
$2\ Sc + 2\ Ag(NO_2) = Ag_2O + Sc_2O_3 + N_2$	-3778
$5\ Zr + 4\ K(NO_3) = 2\ K_2O + 5\ ZrO_2 + 2\ N_2$	-3774
$10\ Cr + 3\ Sr(NO_3)_2 = 3\ SrO + 5\ Cr_2O_3 + 3\ N_2$	-3763
$3\ Mg + 2\ Ag(NO_2) = Ag_2O + 3\ MgO + N_2$	-3760
$5\ Zr + 4\ Rb(NO_3) = 2\ Rb_2O + 5\ ZrO_2 + 2\ N_2$	-3757
$3\ Zr + 2\ Ba(NO_2)_2 = 2\ BaO + 3\ ZrO_2 + 2\ N_2$	-3752
$5\ U + 4\ Cs(NO_3) = 2\ Cs_2O + 5\ UO_2 + 2\ N_2$	-3739
$5\ Si + 4\ Na(NO_3) = 2\ Na_2O + 5\ SiO_2 + 2\ N_2$	-3731
$5\ Si + 2\ Ba(NO_3)_2 = 2\ BaO + 5\ SiO_2 + 2\ N_2$	-3728
$5\ Hf + 4\ Cs(NO_3) = 2\ Cs_2O + 5\ HfO_2 + 2\ N_2$	-3720
$3\ Zr + 4\ Na(NO_2) = 2\ Na_2O + 3\ ZrO_2 + 2\ N_2$	-3702
$11\ Mn + 2\ Pb(NO_3)_2 = Pb_2O + 11\ MnO + 2\ N_2$	-3686
$2\ B + 2\ Ag(NO_2) = Ag_2O + B_2O_3 + N_2$	-3681
$10\ Al + 6\ Cs(NO_3) = 3\ Cs_2O + 5\ Al_2O_3 + 3\ N_2$	-3629
$5\ Th + 4\ Cs(NO_3) = 2\ Cs_2O + 5\ ThO_2 + 2\ N_2$	-3615
$5\ Mn + Ca(NO_3)_2 = CaO + 5\ MnO + N_2$	-3602
$2\ La + Ba(NO_2)_2 = BaO + La_2O_3 + N_2$	-3592
$10\ La + 6\ K(NO_3) = 3\ K_2O + 5\ La_2O_3 + 3\ N_2$	-3588
$5\ Ca + 2\ Li(NO_3) = Li_2O + 5\ CaO + N_2$	-3585
$10\ La + 6\ Rb(NO_3) = 3\ Rb_2O + 5\ La_2O_3 + 3\ N_2$	-3574
$2\ Nd + Ba(NO_2)_2 = BaO + Nd_2O_3 + N_2$	-3557
$10\ Nd + 6\ K(NO_3) = 3\ K_2O + 5\ Nd_2O_3 + 3\ N_2$	-3548
$2\ La + 2\ Na(NO_2) = Na_2O + La_2O_3 + N_2$	-3542

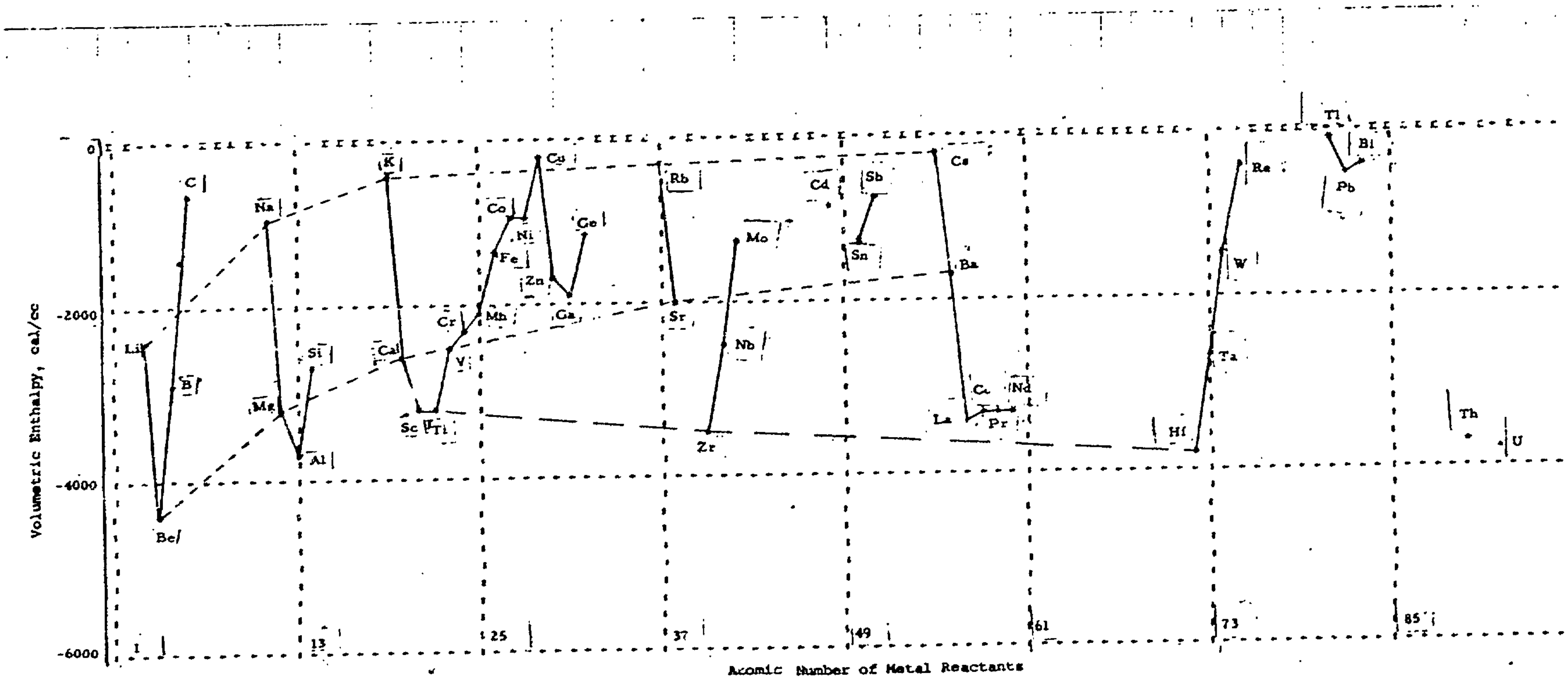


Figure 8

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH $CaNO_3$

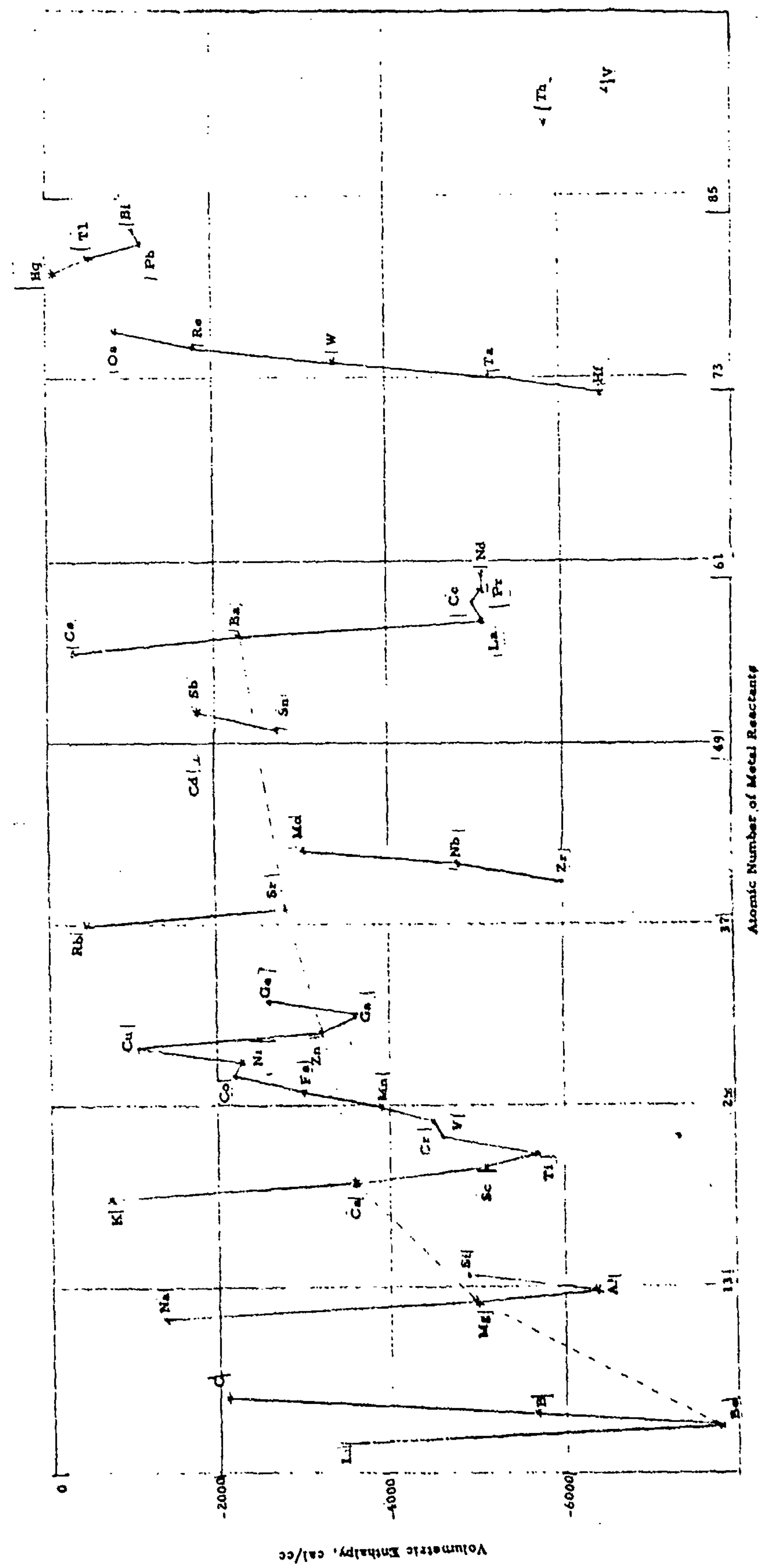


Figure 9

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH $LiNO_3$

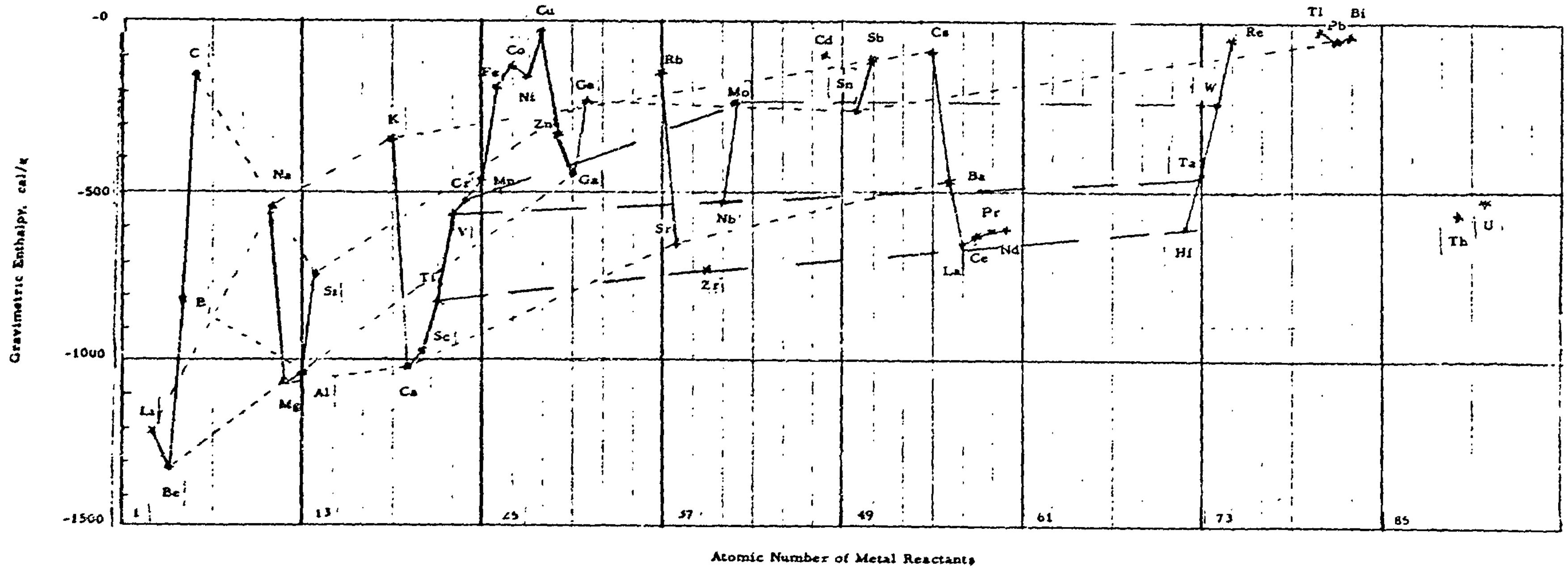


Figure 10

GRAVIMETRIC ENTHALPIES OF REACTIONS OF METALS WITH $CaNO_3$

the products and reactants are the same except for boric oxide and aluminum oxide. Thus the coefficients of the reaction, the heat of formation, the volume of the nitrate, and the volume of the resultant oxide are not involved in the fact that aluminum reactions are more energetic than boron reactions. The remaining factors contributing to the reaction enthalpy are the atomic volumes of boron and aluminum and the heats of formation of boric oxide and aluminum oxide. Since boron's atomic volume, 4.57 cc, is much less than that of aluminum, 9.99 cc, its reactions would be expected to be more energetic. However, the unusually high heat of formation of aluminum oxide compared with that of boric oxide, -399 and -302 kcal, respectively, causes the aluminum reactions to be especially energetic. The effect of the heat of formation is enhanced by the stoichiometric coefficient of these oxides in the balanced equation because these factors multiply the difference between the heats of formation.

Comparison of beryllium and magnesium illustrates this further. Beryllium has a much lower atomic volume than magnesium, 4.94 compared with 13.95 cc. But unlike aluminum and boron, the heat of formation of magnesium oxide is slightly less than that of beryllium oxide, -144 compared with -146 kcal, so that beryllium reactions are more energetic than magnesium reactions. A similar situation in reverse exists with carbon. Its reaction energies are low compared with those of silicon because of the low heat of formation of carbon dioxide compared with that of silicon dioxide, -94 compared with -205 kcal.

Except for these anomalies, the reactions in a group become less energetic with increasing atomic number of the metal reactant. Group I has the least energetic reactions and Group II the most energetic. Group I reactions are not energetic because of the large atomic volumes of the metals and the low heats of formation of the oxides. The Group II and VI reactions are intermediate between the Group I and II extremes.

The dashed lines in Figure 8 connect members of the "short" groups in the periodic table. These groups also have an interesting behavior. In the first three groups in the series, Group IIIB (scandium, yttrium, and lanthanum), Group IVB (titanium, zirconium, and hafnium), and Group VB (vanadium, niobium, and tantalum), the reaction energy increases with increasing atomic number. The remaining groups, Group VIB (chromium, molybdenum, and tungsten), Group VIIB (manganese, technetium, and rhenium), Group VIII (iron, ruthenium, dysprosium, cobalt, rhodium, iridium, nickel, palladium, and platinum), Group IB (copper, silver, and gold), and Group IIB (zinc, cadmium, and mercury), exhibit a decrease in energy with increasing atomic number. The members of Group VIII are not

evident because their reactions in general have a positive enthalpy and are not recorded. As drawn in Figure 8, the dashed lines (only one is drawn in for reference) connecting the members in Groups IIB, IVB, VB, VIB, VIIB, and IIB start with a negative slope for Group IIB and become more positive for each group in the above order. Some of the reasons for this behavior have been discussed previously with respect to the lanthanide contraction.

Figures 9, 10, and 11 illustrate that the reactions of metals with other nitrates or nitrites exhibit the same behavior except for vertical displacement of the ordinate scale. The two nitrates chosen represent the extremes of reaction energy with any particular metal, lithium nitrate (Figure 9) being the most energetic and cesium nitrate (Figure 10) the least energetic of those included in this study.

The gravimetric relationships are essentially the same as the volumetric ones (Figures 9 and 11 versus Figure 10) except for reversal of the magnesium and aluminum energies. Magnesium is more energetic on the gravimetric basis because the small atomic volume of aluminum is not involved. The energy decreases with increasing atomic number of the Group IIB and IVB elements. These elements behave normally on a gravimetric basis because the lanthanide contraction is not involved.

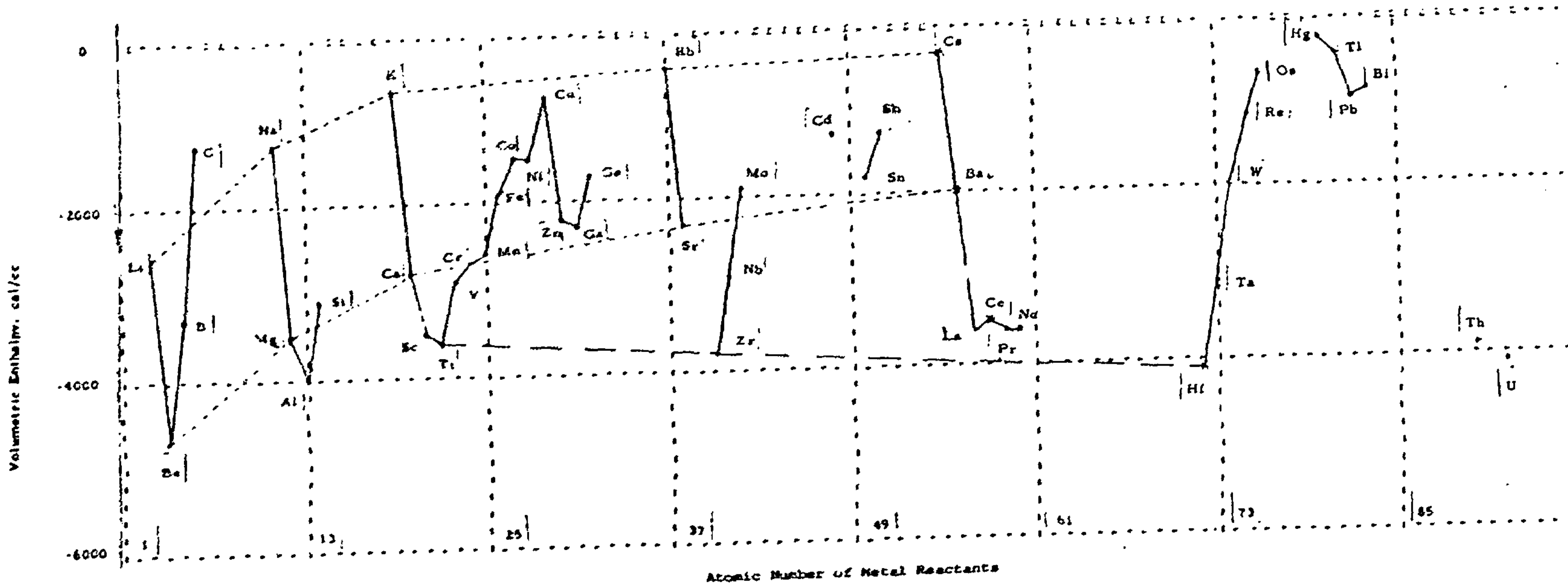


Figure 11

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH $Ba(NO_2)_2$

D. Silicide Reactions

The reactions of various metals with 36 silicides are represented by 302 reactions in the present study. Six typical reactions are shown in Table 13 and the 50 most energetic reactions are shown in Table 14. Table 14 shows that the silicide reactions with barium metal are the most energetic. This is because $BaSi_3$ has an unusually high heat of formation -407 kcal. When barium is the reactant, Ba_2Si_2 may also form and result in a less energetic reaction. Strontium also produces moderately energetic reactions because the heats of formation of $SrSi_2$ and SrSi are -150 and -113 kcal respectively. With the exception of these four silicides, the heats of formation of the silicides for which data are available are very low. In fact, the remainder serve preferentially as reactants because of their low heats of formation.

The periodic behavior of enthalpies of these reactions as typified by the cobalt disilicide reactions is shown in Figure 12. Because of the paucity of data, only the Group II metal reactions are available for comparative purposes. The behavior of the Group II silicides is the reverse of that exhibited by the nitrates and oxides; i.e., magnesium is least energetic and barium is most energetic. This occurs because barium silicide has a much higher heat of formation than magnesium silicide, whereas barium oxide has a lower heat of formation and a larger molecular volume than magnesium oxide.

The gravimetric behavior is shown in Figure 13. It is essentially the same as the volumetric behavior. The energy of the Group II elements increases with increasing atomic number.

Although experimental studies of silicide reactions are of great interest, they would be time-consuming because very few of the reactants are available and would have to be synthesized individually.

Table 13

DATA ON REACTIONS OF VARIOUS METALS WITH SILICIDES

	Sr	+	Co_2Si	=	2 Co	+	SrSi
Heat of formation			-27.60				-113.00
Molecular weight	87.63		145.94		58.94		115.72
Density	2.60		7.28		8.90		
Melting point, °C	770.00		1325.00		1493.00		
Boiling point, °C	1384.00				3100.00		
Heat of reaction, kcal	-85.40						
Reactants' density	4.35						
Gravimetric enthalpy, cal/g	-365.63						
Volumetric enthalpy, cal/cc	-1588.82						

	Sr	+	CoSi	=	Co	+	SrSi
Heat of formation			-24.00				-113.00
Molecular weight	87.63		87.00		58.94		115.72
Density	2.60		6.30		8.90		
Melting point, °C	770.00		1390.00		1493.00		
Boiling point, °C	1384.00				3100.00		
Heat of reaction, kcal	-89.00						
Reactants' density	3.68						
Gravimetric enthalpy, cal/g	-509.65						
Volumetric enthalpy, cal/cc	-1873.16						

	2 Sr	+	$CoSi_2$	=	Co	+	2 SrSi
Heat of formation			-24.60				-113.00
Molecular weight	87.63		115.06		58.94		115.72
Density	2.60		5.30		8.90		
Melting point, °C	770.00		1275.00		1493.00		
Boiling point, °C	1384.00				3100.00		
Heat of reaction, kcal	-201.40						
Reactants' density	3.26						
Gravimetric enthalpy, cal/g	-693.72						
Volumetric enthalpy, cal/cc	-2259.95						

Table 13 (cont.)

	2 Ba	+	3 $CoSi_2$	=	3 Co	+	2 $BaSi_3$
Heat of formation			-24.60				-407.00
Molecular weight	137.36		115.06		58.94		221.63
Density	3.50		5.30		8.90		
Melting point, °C	704.00		1275.00		1493.00		
Boiling point, °C	1638.00				3100.00		
Heat of reaction, kcal	-740.20						
Reactants' density	4.32						
Gravimetric enthalpy, cal/g	-1194.06						
Volumetric enthalpy, cal/cc	-5153.89						

	Ba	+	$CoSi_3$	=	Co	+	$BaSi_3$
Heat of formation			-25.60				-407.00
Molecular weight	137.36		143.21		58.94		221.63
Density	3.50				8.90		
Melting point, °C	704.00		1305.00		1493.00		
Boiling point, °C	1638.00				3100.00		
Heat of reaction, kcal	-381.40						
Reactants' density							
Gravimetric enthalpy, cal/g	-1359.38						
Volumetric enthalpy, cal/cc							

	Ba	+	3 FeSi	=	3 Fe	+	$BaSi_3$
Heat of formation			-19.20				-407.00
Molecular weight	137.36		83.91		55.85		221.63
Density	3.50		6.10		7.86		
Melting point, °C	704.00		1430.00		1535.00		
Boiling point, °C	1638.00				2800.00		
Heat of reaction, kcal	-349.40						
Reactants' density	4.83						
Gravimetric enthalpy, cal/g	-897.99						
Volumetric enthalpy, cal/cc	-4339.68						

Table 14

MOST ENERGETIC SILICIDE REACTIONS* WITH METALS, IN TERMS OF VOLUMETRIC ENTHALPY

Reactant	Product	Enthalpy, cal/cc
3 $CoSi_2$	2 $BaSi_3$	-5153
3 FeSi	$BaSi_3$	-4339
3 $ZrSi_2$	2 $BaSi_3$	-4174
3 CoSi	$BaSi_3$	-4152
3 $CaSi_2$	2 $BaSi_3$	-3639
$CoSi_2$	Ba_2Si_2	-3417
3 Co_2Si	$BaSi_3$	-3262
2 FeSi	Ba_2Si_2	-3099
3 Ni_2Si	$BaSi_3$	-3065
$ZrSi_2$	Ba_2Si_2	-3045
2 CoSi	Ba_2Si_2	-3006
$CaSi_2$	Ba_2Si_2	-2829
2 Cu_2Si	Ba_2Si_2	-2629
2 Ni_2Si	Ba_2Si_2	-2521
$CoSi_2$	$SrSi_2$	-2263
$CoSi_2$	2 SrSi	-2259
FeSi	SrSi	-1976
$ZrSi_2$	2 SrSi	-1946
CoSi	SrSi	-1873
2 FeSi	$SrSi_2$	-1823
$CaSi_2$	2 SrSi	-1793
$ZrSi_2$	$SrSi_2$	-1783
2 CoSi	$SrSi_2$	-1663
Co_2Si	SrSi	-1588
$CaSi_2$	$SrSi_2$	-1578
Ni_2Si	SrSi	-1472

Table 14 (cont.)

Reactant	Product	Enthalpy, cal/cc
2 Co_2Si	$SrSi_2$	-1284
2 Ni_2Si	$SrSi_2$	-1117
3 $CoSi_2$	2 Zr_5Si_3	-1055
$CoSi_2$	2 Zr_2Si	- 957
$CoSi_2$	2 ZrSi	- 916
$CoSi_2$	2 Ni_2Si	- 885
3 FeSi	Zr_5Si_3	- 789
$CoSi_2$	2 Ni_3Si	- 757
FeSi	Zr_2Si	- 728
3 $CaSi_2$	2 Zr_5Si_3	- 716
$CaSi_2$	2 Zr_2Si	- 670
3 CoSi	Zr_5Si_3	- 661
$CoSi_2$	Ca_2Si_2	- 645
$CoSi_2$	2 CaSi	- 645
CoSi	Zr_2Si	- 614
$CoSi_2$	2 Ca_2Si	- 602
FeSi	ZrSi	- 574
$ZrSi_2$	2 Ni_2Si	- 551
FeSi	Ni_2Si	- 534
$CaSi_2$	2 ZrSi	- 516
$ZrSi_2$	2 Ni_3Si	- 501
FeSi	Ni_3Si	- 485
3 Co_2Si	Zr_5Si_3	- 484
$CaSi_2$	2 Ni_2Si	- 480

*The first reaction, for example, is:
2 Ba + 3 $CoSi_2$ = 3 Co + 2 $BaSi_3$.

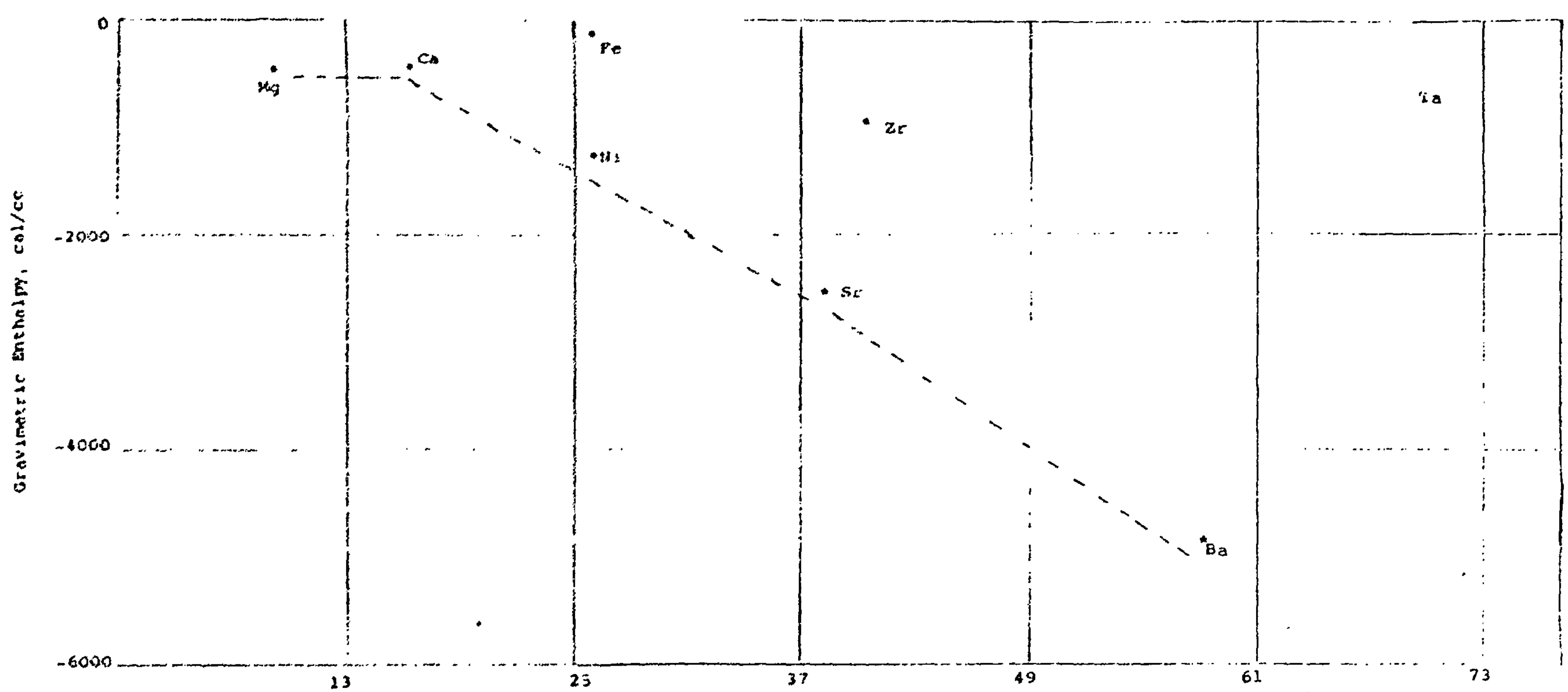


Figure 12

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH $CoSi_2$

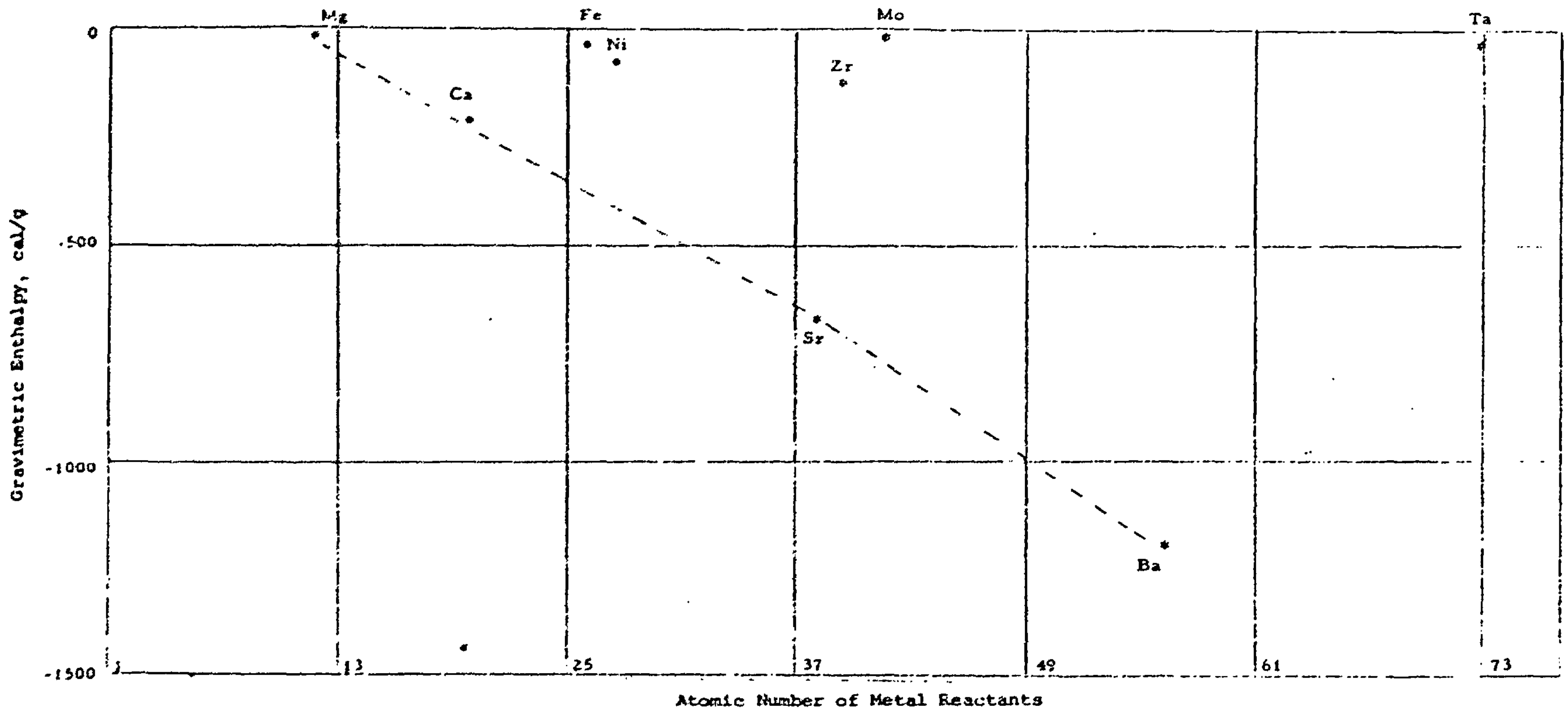


Figure 13

GRAVIMETRIC ENTHALPIES OF REACTIONS OF METALS WITH $CoSi_2$

E. Carbide Reactions

Based on the data available for 30 carbides, 386 reactions were analyzed. The carbide reactions are not a very energetic class. The most energetic reactions are listed in Table 15. Tantalum, titanium, and zirconium are the most energetic metal reactants, forming tantalum carbide, titanium carbide, and zirconium carbide, respectively. Many different carbides, e.g., lithium carbide, vanadium carbide, tungsten carbide, calcium carbide, and trichromium dicarbide, perform as useful reactants. Three representative reactions are shown in Table 16.

The reactions of a few of the metals with lithium carbide are shown in Figure 14. Although no useful correlations can be made because of the lack of data, Figure 14 does show that tantalum, titanium, and zirconium are the most energetic metals in these systems.

Table 15

MOST ENERGETIC CARBIDE REACTIONS* WITH METALS, IN TERMS OF VOLUMETRIC ENTHALPY

Reactant	Product	Enthalpy, cal/cc
Li_2C_2	2 TaC	-2532
VC	TaC	-2351
WC	TaC	-2334
CaC_2	2 TaC	-2222
Cr_3C_2	2 TaC	-2186
Ni_3C	TaC	-2165
Li_2C_2	2 TiC	-2119
Mo_2C	TaC	-2056
Na_2C_2	2 TaC	-1987
Fe_3C	TaC	-1956
WC	TiC	-1937
VC	TiC	-1925
UC_2	2 TaC	-1900
Ni_3C	TiC	-1896
CaC_2	2 TiC	-1853
Cr_3C_2	2 TiC	-1803
Mo_2C	TiC	-1774
Mn_3C	TaC	-1717
Al_4C_3	3 TaC	-1713
Na_2C_2	2 TiC	-1705
Fe_3C	TiC	-1690
ThC_2	2 TaC	-1639
SiC	TaC	-1588

Table 15 (cont.)

Reactant	Product	Enthalpy, cal/cc
B_4C	TaC	-1508
UC_2	2 TiC	-1482
Ni_3C	ZrC	-1477
Li_2C_2	2 ZrC	-1472
Mn_3C	TiC	-1459
Al_4C_3	3 TiC	-1411
Ni_3C	UC	-1402
Li_2C_2	2 UC	-1358
Mo_2C	ZrC	-1351
WC	ZrC	-1340
CaC_2	2 ZrC	-1307
Fe_3C	ZrC	-1298
VC	ZrC	-1291
Na_2C_2	2 ZrC	-1289
Mo_2C	UC	-1267
ThC_2	2 TiC	-1263
Cr_3C_2	2 ZrC	-1244
NbC	TaC	-1237
WC	UC	-1223
B_4C	TiC	-1220
Fe_3C	UC	-1216
Na_2C_2	2 UC	-1202
CaC_2	2 UC	-1196
SiC	TiC	-1181
VC	UC	-1163
Cr_3C_2	2 UC	-1125
Mn_3C	ZrC	-1102

*The first reaction, for example, is:
$2\ Ta + Li_2C_2 = 2\ Li + 2\ TaC$.

Table 16

DATA ON REACTIONS OF VARIOUS METALS WITH CARBIDES

	2 Ta	+	Li_2C_2	=	2 Li	+	2 TaC
Heat of formation			-14.20				-63.80
Molecular weight	180.95		37.90		6.94		192.87
Density	16.60		1.65		0.53		14.65
Melting point, °C	2977.00				180.00		3827.00
Boiling point, °C	4100.00				1326.00		5500.00
Heat of reaction, kcal	-113.40						
Reactants' density	8.93						
Gravimetric enthalpy, cal/g	-283.64						
Volumetric enthalpy, cal/cc	-2532.90						

	3 Ta	+	Mg_2C_3	=	2 Mg	+	3 TaC
Heat of formation			19.00				-63.80
Molecular weight	180.95		84.67		24.32		192.87
Density	16.60				1.74		14.65
Melting point, °C	2977.00				650.00		3827.00
Boiling point, °C	4100.00				1120.00		5500.00
Heat of reaction, kcal	-210.40						
Reactants' density							
Gravimetric enthalpy, cal/g	-335.29						
Volumetric enthalpy, cal/cc							

	2 Ta	+	MgC_2	=	Mg	+	2 TaC
Heat of formation			21.00				-63.80
Molecular weight	180.95		48.34		24.32		192.87
Density	16.60				1.74		14.65
Melting point, °C	2977.00				650.00		3827.00
Boiling point, °C	4100.00				1120.00		5500.00
Heat of reaction, kcal	-148.60						
Reactants' density							
Gravimetric enthalpy, cal/g	-362.23						
Volumetric enthalpy							

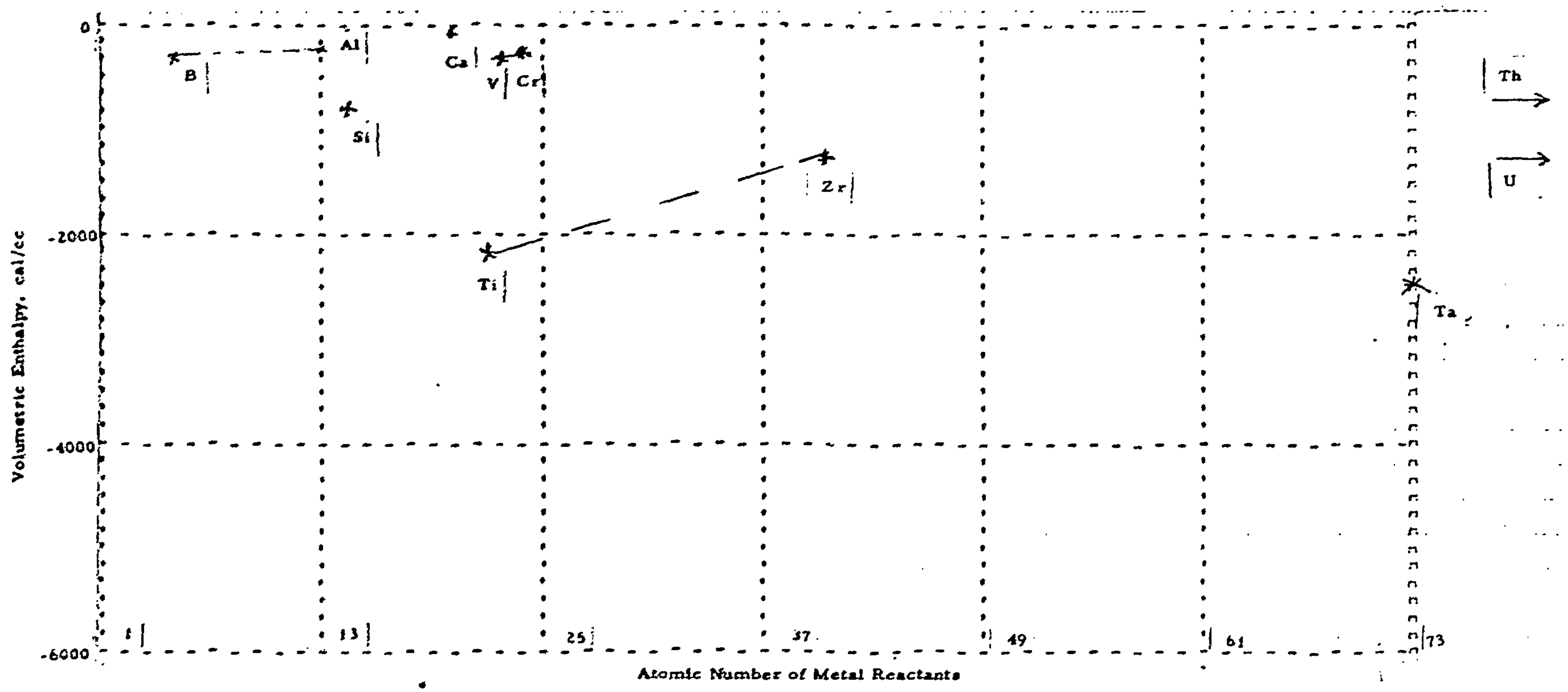


Figure 14

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH LiC_2

F. Sulfide Reactions

The data for 68 sulfides were used to calculate the enthalpies of 2145 reactions of sulfides with metals. These reactions are, in general, only moderately energetic. The 50 most energetic reactions are shown in Table 17. The reactions of iron disulfide with thorium, cesium, and lanthanum are the most energetic. The energies of these reactions are not considered high for pyrotechnic materials but are high enough to warrant a modest experimental study. In most cases several sulfide products, involving different valences of the metals, form from the same two reactants. It would be interesting to determine which reactions predominate, since this will define the experimental reaction energy This energy is a function of the kinetics of the reaction and the thermodynamic equilibrium based on free energies. A few representative reactions are shown in Table 18.

Figure 15 illustrates the periodic relationships between the reactions of metals with iron disulfide. The relationship is essentially the same as that among the nitrate reactions except for some differences with the low-atomic number metals. For instance, in the sulfide systems the Group II metals exhibit a maximum energy output at calcium, whereas in the nitrate systems beryllium and magnesium are more energetic than calcium. In the nitrate systems, the energy output based on the volume of reactants decreases in going from beryllium to barium because the product oxides all have approximately the same heats of formation, -133 to -152 kcal, and the reactant metals increase in atomic volume, 4.74 to 39.2 cc. In the sulfide systems, the effect of the reactant volumes is the same, but the heats of formation vary widely, with a pronounced maximum (-115 kcal) at calcium sulfide and a minimum (-56 kcal) at beryllium sulfide. In this case, the effect of the heats of formation predominates and the energy outputs also have a maximum at calcium. Another interesting difference between the sulfide and nitrate systems is that in the former aluminum is less energetic than magnesium and in the latter the reverse is true. This phenomenon results from the unusually high heat of formation of aluminum oxide, -399 kcal.

Table 17

MOST ENERGETIC SULFIDE REACTIONS* WITH METALS, IN TERMS OF VOLUMETRIC ENTHALPY

Reactant	Product	Enthalpy, cal/cc
7 FeS_2	2 Th_4S_7	-3169
2 FeS_2	Ce_3S_4	-3104
7 FeS_2	2 Th_4S_7	-3093
3 FeS_2	2 Ce_2S_3	-3089
FeS_2	2 ThS	-3074
3 FeS_2	2 La_2S_3	-3061
2 FeS_2	Ce_3S_4	-3038
3 FeS_2	2 Ce_2S_3	-3018
FeS_2	2 ThS	-3018
FeS_2	2 CeS	-2995
3 FeS_2	2 La_2S_3	-2993
FeS_2	2 CeS	-2939
FeS_2	ThS_2	-2935
7 Co_2S_3	3 Th_4S_7	-2920
Co_2S_3	3 ThS	-2894
4 Ce_2S_3	3 Ce_3S_4	-2892
Co_2S_3	Ce_2S_3	-2865
FeS_2	ThS_2	-2851
Ce_2S_3	La_2S_3	-2849
Co_2S_3	3 CeS	-2822
Co_3S_4	4 ThS	-2781
7 Co_3S_4	4 Th_4S_7	-2769
Co_3S_4	Ce_3S_4	-2760
3 Co_3S_4	4 Ce_2S_3	-2726
3 Co_3S_4	4 La_2S_3	-2715
Co_3S_4	4 CeS	-2711

Table 17 (cont.)

Reactant	Product	Enthalpy, cal/cc
NiS	ThS	-2708
2 Co_2S_3	3 ThS_2	-2695
4 NiS	Ce_3S_4	-2678
7 NiS	Th_4S_7	-2675
CoS	ThS	-2667
NiS	CeS	-2641
3 NiS	Ce_2S_3	-2641
3 FeS_2	2 Th_2S_3	-2636
3 NiS	La_2S_3	-2633
4 CoS	Ce_3S_4	-2630
7 CoS	Th_4S_7	-2621
ReS_2	2 ThS	-2615
CuS	ThS	-2612
CoS	CeS	-2600
WS_2	2 ThS	-2599
3 CoS	Ce_2S_3	-2590
3 CoS	La_2S_3	-2584
4 CuS	Ce_3S_4	-2571
2 ReS_2	Ce_3S_4	-2570
FeS_2	CeS_2	-2568
CS_2	2 ThS	-2563
3 FeS_2	2 Th_2S_3	-2560
7 CuS	Th_4S_7	-2556
7 ReS_2	2 Th_4S_7	-2553

*The first reaction, for example, is:
$8\ Th + 7\ FeS_2 = 7\ Fe + 2\ Th_4S_7$.

Table 18

DATA ON REACTIONS OF VARIOUS METALS WITH SULFIDES

	3 Ce	+	2 FeS_2	=	2 Fe	+	Ce_3S_4
Heat of formation			-36.88				-421.50
Molecular weight	140.13		119.98		55.85		548.65
Density	6.70		4.87		7.86		
Melting point, °C	775.00		450.00		1535.00		2050.00
Boiling point, °C	2900.00				2800.00		
Heat of reaction, kcal	-347.74						
Reactants' density	5.90						
Gravimetric enthalpy, cal/g	-526.60						
Volumetric enthalpy, cal/cc	-3104.33						

	3 Ce	+	2 FeS_2	=	2 Fe	+	Ce_3S_4
Heat of formation			-42.52				-421.50
Molecular weight	140.13		119.98		55.85		548.65
Density	6.70		5.00		7.86		
Melting point, °C	775.00		1171.00		1535.00		2050.00
Boiling point, °C	2900.00				2800.00		
Heat of reaction, kcal	-336.46						
Reactants' density	5.96						
Gravimetric enthalpy, cal/g	-509.52						
Volumetric enthalpy, cal/cc	-3038.38						

	3 Ce	+	4 GaS	=	4 Ga	+	Ce_3S_4
Heat of formation			-46.40				-421.50
Molecular weight	140.13		101.79		69.72		548.65
Density	6.70		3.86		5.90		
Melting point, °C	775.00		965.00		29.78		2050.00
Boiling point, °C	2900.00				937.00		
Heat of reaction, kcal	-235.90						
Reactants' density	4.92						
Gravimetric enthalpy, cal/g	-285.06						
Volumetric enthalpy, cal/cc	-1402.27						

Table 18 (cont.)

	8 Th	+ 7 FeS_2	= 7 Fe	+ 2 Th_4S_7
Heat of formation		-36.88		-665.00
Molecular weight	232.00	119.98	55.85	1152.46
Density	11.20	4.87	7.86	
Melting point, °C	1840.00	450.00	1535.00	2027.00
Boiling point, °C	4500.00		2800.00	
Heat of reaction, kcal	-1071.84			
Reactants' density	7.97			
Gravimetric enthalpy, cal/g	-397.59			
Volumetric enthalpy, cal/cc	-3169.53			

	8 Th	+ 7 FeS_2	= 7 Fe	+ 2 Th_4S_7
Heat of formation		-42.52		-665.00
Molecular weight	232.00	119.98	55.85	1152.46
Density	11.20	5.00	7.86	
Melting point, °C	1840.00	1171.00	1535.00	2027.00
Boiling point, °C	4500.00		2800.00	
Heat of reaction, kcal	-1032.36			
Reactants' density	8.08			
Gravimetric enthalpy, cal/g	-382.94			
Volumetric enthalpy, cal/cc	-3093.80			

	4 Th	+ 7 GaS	= 7 Ga	+ Th_4S_7
Heat of formation		-46.40		-665.00
Molecular weight	232.00	101.79	69.72	1152.46
Density	11.20	3.86	5.90	
Melting point, °C	1840.00	965.00	29.78	2027.00
Boiling point, °C	4500.00		937.00	
Heat of reaction, kcal	-340.20			
Reactants' density	6.13			
Gravimetric enthalpy, cal/g	-207.37			
Volumetric enthalpy, cal/cc	-1272.01			

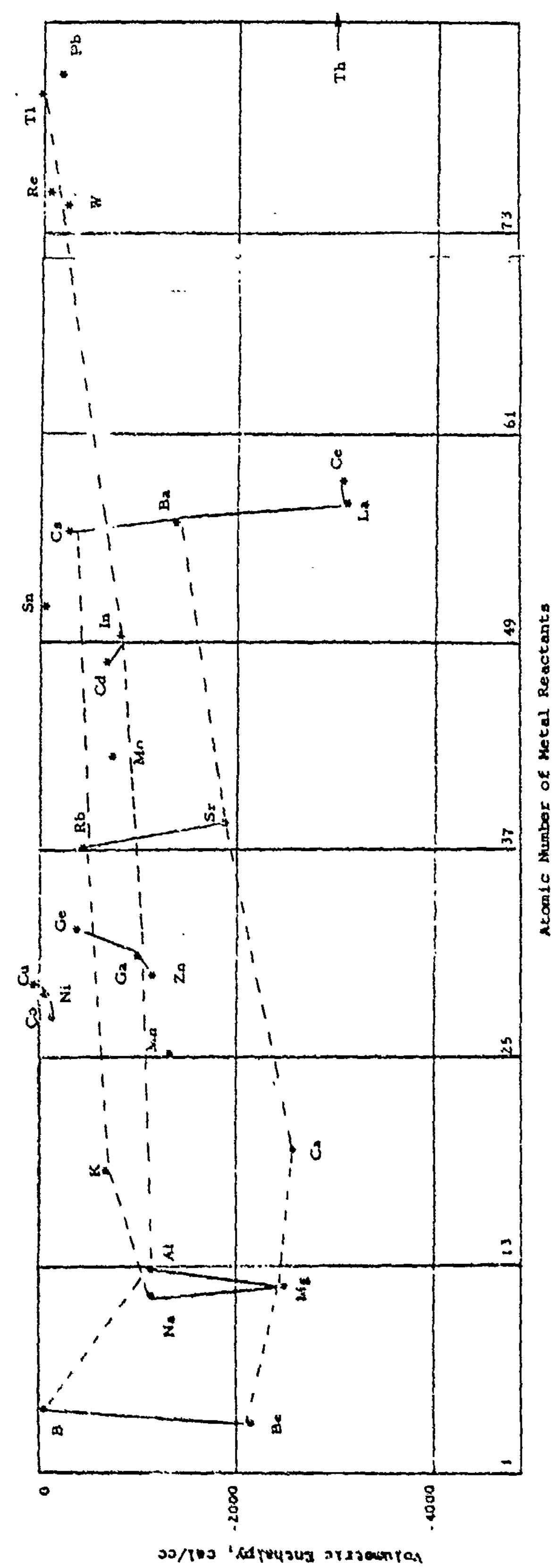


Figure 15

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH FeS_2

G. Nitride and Azide Reactions

The data for 44 nitrides and 13 azides were used to compute the enthalpies of 1575 reactions. These reactions, like the sulfides, are only moderately energetic and appear to warrant only a modest experimental study. Caution must be excerised in experimental work because many of the azide compounds are very reactive. The 50 most energetic reactions are listed in Table 19. The reactions of barium azide (BaN_6 or $Ba(N_3)_2$) with beryllium, yttrium, titanium, zirconium, hafnium, thorium, and aluminum metal are the most energetic. The reactions of iron nitride with these metals are also fairly energetic.

Several representative reactions are shown in Table 20. Certain interesting relationships are apparent. For instance, the azide or nitride of barium can be used as the reactant. The azide is more energetic because it has a lower heat of formation. Copper can also be used as a nitride or azide, but not enough data are available to calculate the volumetric enthalpies. On a gravimetric basis, the reaction of copper azide with titanium is highly energetic. In some cases more than one nitride can be used as a reactant or is formed as a product from the same reactant metal. This is illustrated by the iron nitrides, Fe_2N and Fe_4N.

The periodic relationships of the reactions with barium azide and with the iron nitride Fe_2N are shown in Figures 16 and 17. Although all the possible lines have not been drawn, it is evident that except for minor deviations the behavior of these systems closely resembles that of the oxide and nitrate systems. This is especially apparent in Groups II and III: aluminum is more energetic than magnesium.

Table 19

MOST ENERGETIC NITRIDE AND AZIDE REACTIONS* WITH METALS, IN TERMS OF VOLUMETRIC ENTHALPY

Reactant	Product	Enthalpy, cal/cc
BaN_6	3 Be_3N_2	-3346
BaN_6	2 U_2N_3	-3308
BaN_6	6 UN	-3109
BaN_6	6 TiN	-3087
BaN_6	6 ZrN	-3014
BaN_6	6 HfN	-2961
2 BaN_6	3 Th_3N_4	-2692
BaN_6	6 AlN	-2499
3 Fe_2N	U_2N_3	-2478
2 Fe_2N	Be_3N_2	-2470
BaN_6	NbN_6	-2460
BaN_6	6 YN	-2444
Fe_2N	UN	-2431
BaN_6	6 TaN	-2423
Fe_2N	ZrN	-2387
Fe_2N	TiN	-2368
Fe_2N	HfN	-2330
BaN_6	6 CeN	-2298
BaN_6	6 ScN	-2182
4 Fe_2N	Th_3N_4	-2153
CrN	UN	-2098
3 CrN	U_2N_3	-2093
GaN	UN	-2078
3 GaN	U_2N_3	-2070
CrN	ZrN	-2059

Table 19 (cont.)

Reactant	Product	Enthalpy, cal/cc
2 CrN	Be_3N_2	-2057
GaN	ZrN	-2044
2 BaN_6	3 Si_3N_4	-2037
2 GaN	Be_3N_2	-2037
BaN_6	6 LaN	-2012
BN	UN	-1994
CrN	TiN	-1978
CrN	HfN	-1970
GaN	TiN	-1969
3 BN	U_2N_3	-1967
Fe_2N	YN	-1964
GaN	HfN	-1963
BN	ZrN	-1961
2 BN	Be_3N_2	-1922
Fe_2N	AlN	-1907
Fe_2N	CeN	-1901
Fe_2N	NbN	-1894
BaN_6	6 YN	-1878
BN	HfN	-1869
Fe_2N	TaN	-1866
BN	TiN	-1864
BaN_6	6 BN	-1795
4 GaN	Th_3N_4	-1777
Fe_2N	ScN	-1776
4 CrN	Th_3N_4	-1766

*The first reaction, for example, is:
$9\ Be + BaN_6 = Ba + 3\ Be_3N_2$

N_6 represents the azide $(N_3)_2$

Table 20

DATA ON REACTIONS OF VARIOUS METALS WITH NITRIDES AND AZIDES

	3 Be	+	2 AlN	=	2 Al	+	Be_3N_2
Heat of formation			-57.70				-135.70
Molecular weight	9.01		40.98		26.98		55.06
Density	1.85		3.26		2.70		
Melting point, °C	1283.00		220.00		660.00		2200.00
Boiling point, °C	2970.00				2327.00		2240.00
Heat of reaction, kcal	-20.30						
Reactants' density	2.74						
Gravimetric enthalpy, cal/g	-186.24						
Volumetric enthalpy, cal/cc	-510.60						

	3 Be	+	2 BN	=	2 B	+	Be_3N_2
Heat of formation			-32.10				-135.70
Molecular weight	9.01		24.83		10.82		55.06
Density	1.85		2.20		2.37		
Melting point, °C	1283.00				2040.00		2200.00
Boiling point, °C	2970.00				2550.00		2240.00
Heat of reaction, kcal	-71.50						
Reactants' density	2.06						
Gravimetric enthalpy, cal/g	-932.22						
Volumetric enthalpy, cal/cc	-1922.64						

	9 Be	+	BaN_6	=	Ba	+	3 Be_3N_2
Heat of formation			-8.00				-135.70
Molecular weight	9.01		221.41		137.36		55.06
Density	1.85		2.94		3.50		
Melting point, °C	1283.00				704.00		2200.00
Boiling point, °C	2970.00				1638.00		2240.00
Heat of reaction, kcal	-399.10						
Reactants' density	2.54						
Gravimetric enthalpy, cal/g	-1319.22						
Volumetric enthalpy, cal/cc	-3346.49						

Table 20 (cont.)

	3 Be	+	2 Fe_2N	=	4 Fe	+	Be_3N_2
Heat of formation			-.90				-135.70
Molecular weight	9.01		125.71		55.85		55.06
Density	1.85		6.35		7.86		
Melting point, °C	1283.00				1535.00		2200.00
Boiling point, °C	2970.00				2800.00		2240.00
Heat of reaction, kcal	-133.90						
Reactants' density	5.14						
Gravimetric enthalpy, cal/g	-480.86						
Volumetric enthalpy, cal/cc	-2470.05						

	3 Be	+	2 Fe_4N	=	8 Fe	+	Be_3N_2
Heat of formation			-2.55				-135.70
Molecular weight	9.01		237.41		55.85		55.06
Density	1.85		6.57		7.86		
Melting point, °C	1283.00				1535.00		2200.00
Boiling point, °C	2970.00				2800.00		2240.00
Heat of reaction, kcal	-130.60						
Reactants' density	5.78						
Gravimetric enthalpy, cal/g	-260.23						
Volumetric enthalpy, cal/cc	-1503.11						

	3 Be	+	2 GaN	=	2 Ga	+	Be_3N_2
Heat of formation			-25.00				-135.70
Molecular weight	9.01		83.73		69.72		55.06
Density	1.85		6.10		5.90		
Melting point, °C	1283.00				29.78		2200.00
Boiling point, °C	2970.00				937.00		2240.00
Heat of reaction, kcal	-85.70						
Reactants' density	4.62						
Gravimetric enthalpy, cal/g	-440.62						
Volumetric enthalpy, cal/cc	-2037.17						

Table 20 (cont.)

	6 Ti	+	BaN_6	=	Ba	+	6 TiN
Heat of formation			-8.00				-73.00
Molecular weight	47.90		221.41		137.36		61.91
Density	4.50		2.94		3.50		5.43
Melting point, °C	1812.00				704.00		2927.00
Boiling point, °C	3000.00				1638.00		
Heat of reaction, kcal	-430.00						
Reactants' density	3.65						
Gravimetric enthalpy, cal/g	-845.11						
Volumetric enthalpy, cal/cc	-3087.33						

	2 Ti	+	Ba_3N_2	=	3 Ba	+	2 TiN
Heat of formation			-86.90				-73.00
Molecular weight	47.90		440.10		137.36		61.91
Density	4.50				3.50		5.43
Melting point, °C	1812.00		1000.00		704.00		2927.00
Boiling point, °C	3000.00				1638.00		
Heat of reaction, kcal	-59.10						
Reactants' density							
Gravimetric enthalpy, cal/g	-110.28						
Volumetric enthalpy, cal/cc							

	2 Ti	+	Be_3N_2	=	3 Be	+	2 TiN
Heat of formation			-135.70				-73.00
Molecular weight	47.90		55.06		9.01		61.91
Density	4.50				1.85		5.43
Melting point, °C	1812.00		200.00		1283.00		2927.00
Boiling point, °C	3000.00		2240.00		2970.00		
Heat of reaction, kcal	-10.30						
Reactants' density							
Gravimetric enthalpy, cal/g	-68.28						
Volumetric enthalpy, cal/cc							

Table 20 (cont.)

	Ti	+	Cu_3N	=	3 Cu	+	TiN
Heat of formation			17.80				-73.00
Molecular weight	47.90		204.63		63.54		61.91
Density	4.50				8.92		5.43
Melting point, °C	1812.00				1083.00		2927.00
Boiling point, °C	3000.00				2582.00		
Heat of reaction, kcal	-90.80						
Reactants' density							
Gravimetric enthalpy, cal/g	-359.56						
Volumetric enthalpy, cal/cc							

	3 Ti	+	CuN_3	=	Cu	+	3 TiN
Heat of formation			60.50				-73.00
Molecular weight	47.90		105.56		63.54		61.91
Density	4.50				8.92		5.43
Melting point, °C	1812.00				1083.00		2927.00
Boiling point, °C	3000.00				2582.00		
Heat of reaction, kcal	-279.50						
Reactants' density							
Gravimetric enthalpy, cal/g	-1121.30						
Volumetric enthalpy, cal/cc							

	Ti	+	Fe_2N	=	2 Fe	+	TiN
Heat of formation			-.90				-73.00
Molecular weight	47.90		125.71		55.85		61.91
Density	4.50		6.35		7.86		5.43
Melting point, °C	1812.00				1535.00		2927.00
Boiling point, °C	3000.00				2800.00		
Heat of reaction, kcal	-72.10						
Reactants' density	5.70						
Gravimetric enthalpy, cal/g	-415 30						
Volumetric enthalpy, cal/cc	-2368.49						

Table 20 (cont.)

	Zr	+	AlN	=	Al	+	ZrN
Heat of formation			-57.70				-82.20
Molecular weight	91.22		40.98		26.98		105.23
Density	6.40		3.26		2.70		7.09
Melting point, °C	1852.00		220.00		660.00		2952.00
Boiling point, °C	2900.00				2327.00		
Heat of reaction, kcal	-24.50						
Reactants' density	4.93						
Gravimetric enthalpy, cal/g	-185.22						
Volumetric enthalpy, cal/cc	-913.37						

	Zr	+	BN	=	B	+	ZrN
Heat of formation			-32.10				-82.20
Molecular weight	91.22		24.83		10.82		105.23
Density	6.40		2.20		2.38		7.09
Melting point, °C	1852.00				2040.00		2952.00
Boiling point, °C	2900.00				2550.00		
Heat of reaction, kcal	-50.10						
Reactants' density	4.54						
Gravimetric enthalpy, cal/g	-431.71						
Volumetric enthalpy, cal/cc	-1961.67						

	6 Zr	+	BaN_6	=	Ba	+	6 ZrN
Heat of formation			-8.00				-82.20
Molecular weight	91.22		221.41		137.36		105.23
Density	6.40		2.94		3.50		7.09
Melting point, °C	1852.00				704.00		2952.00
Boiling point, °C	2900.00				1638.00		
Heat of reaction, kcal	-485.20						
Reactants' density	4.78						
Gravimetric enthalpy, cal/g	-631.17						
Volumetric enthalpy, cal/cc	-3014.96						

Table 20 (cont.)

	Zr	+	Cu_3N	=	3 Cu	+	ZrN
Heat of formation			17.80				-82.20
Molecular weight	91.22		204.63		63.54		105.23
Density	6.40				8.92		7.09
Melting point, °C	1852.00				1083.00		2952.00
Boiling point, °C	2900.00				2582.00		
Heat of reaction, kcal	-100.00						
Reactants' density							
Gravimetric enthalpy, cal/g	-338.01						
Volumetric enthalpy, cal/cc							

	3 Zr	+	CuN_3	=	Cu	+	3 ZrN
Heat of formation			60.50				-82.20
Molecular weight	91.22		105.56		63.54		105.23
Density	6.40				8.92		7.09
Melting point, °C	1852.00				1083.00		2952.00
Boiling point, °C	2900.00				2582.00		
Heat of reaction, kcal	-307.10						
Reactants' density							
Gravimetric enthalpy, cal/g	-809.81						
Volumetric enthalpy, cal/cc							

	Zr	+	Fe_2N	=	2 Fe	+	ZrN
Heat of formation			-.90				-82.20
Molecular weight	91.22		125.71		55.85		105.23
Density	6.40		6.35		7.86		7.09
Melting point, °C	1852.00				1535.00		2952.00
Boiling point, °C	2900.00				2800.00		
Heat of reaction, kcal	-81.30						
Reactants' density	6.37						
Gravimetric enthalpy, cal/g	-374.78						
Volumetric enthalpy, cal/cc	-2387.67						

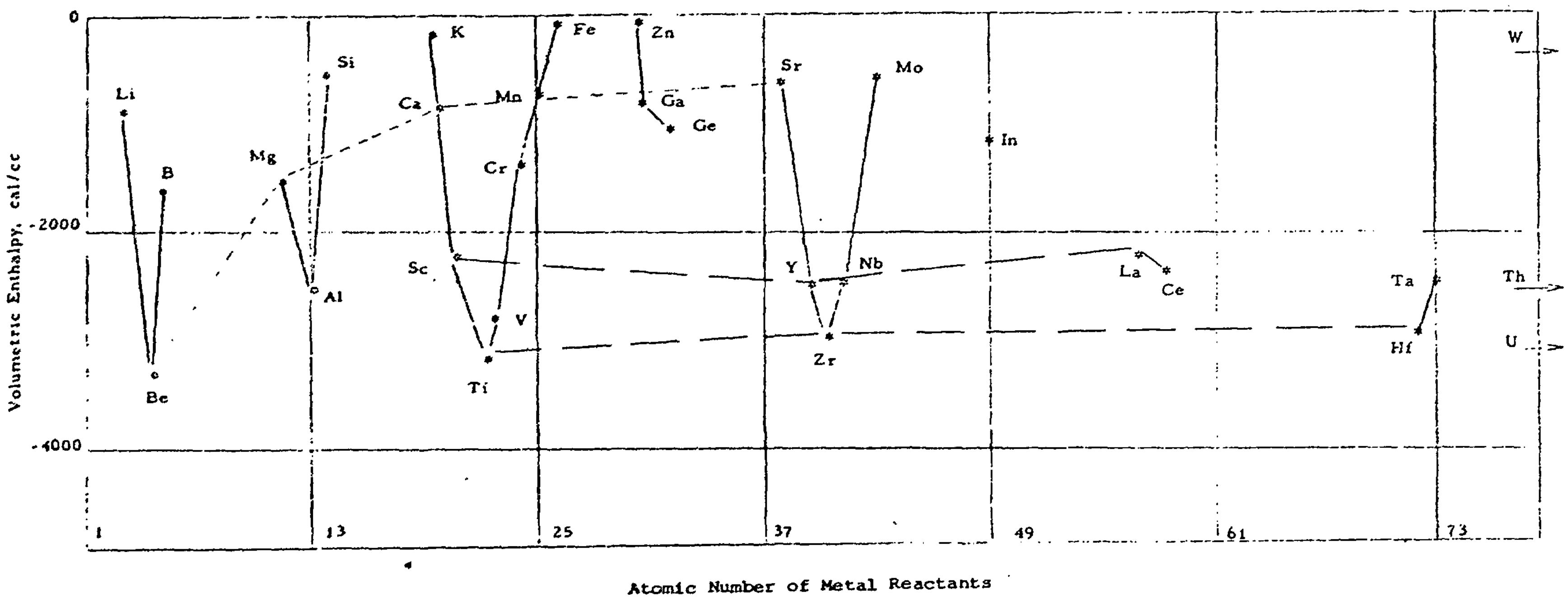


Figure 16

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH $Ba(N_3)_2$

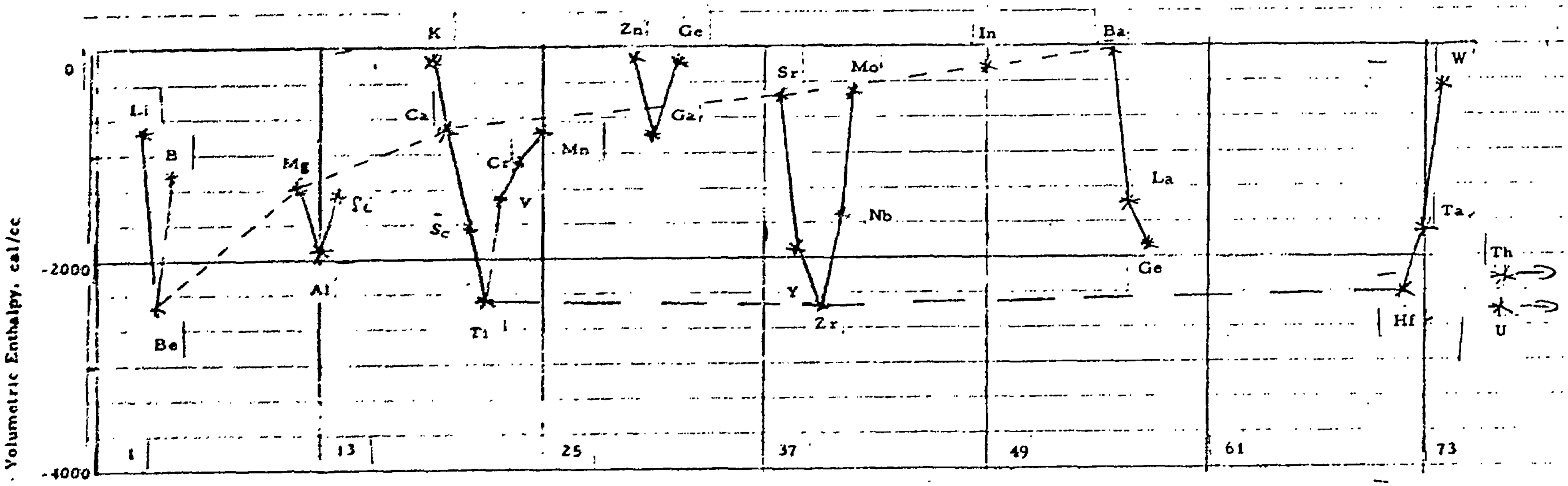


Figure 17

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH Fe_2N

H. Chlorate and Perchlorate Reactions

The possible reactions of 50 metals with 7 chlorates and 9 perchlorates resulted in the computation of 16,384 reactions. Only 801 of them were printed, because reactions with positive enthalpies were discarded, as were those with the lowest enthalpy from the possible combinations of each pair of reactants. Examples of the computer output for some of the more energetic reactions are shown in Table 21.

Chlorates and perchlorates are combinations of chlorine and oxygen systems. The chloride of the metal reactant is rarely produced, and when it is produced, it is in a very low ratio compared with its oxide. For example, note the reaction between beryllium and silver chlorate in Table 22. This occurs because the oxides of the highly reactant metals generally have higher negative heats of formation than the chlorides.

The chlorates and perchlorates are much more energetic than the comparable oxide systems. In fact, they are the most energetic systems examined. The 200 most energetic reactions are shown in Tables 22 and 23. The most energetic reaction, between beryllium and magnesium perchlorate, has a volumetric enthalpy of -9459 cal/cc, which is appreciably higher than the most energetic oxide and nitrate reactions: beryllium with ruthenium oxide, -7800 cal/cc: and beryllium with lithium nitrate, -7798 cal/cc. The beryllium-lithium perchlorate reaction, -9088 cal/cc, which is the next most energetic perchlorate reaction, compares with the beryllium-lithium nitrate reaction

The chlorates and perchlorates are listed in order of their effective energies in Table 24. In general, the perchlorate of a metal is more energetic than the chlorate. Silver is an exception because the chlorate has a much higher density than the perchlorate, and thus on a volumetric basis the chlorate is more energetic than the perchlorate.

The periodic trends in the gravimetric and volumetric enthalpies are shown in Figure 18 for reactions of all the metals with magnesium perchlorate. The trends are almost the same as those in the nitrate and oxide systems The most energetic reactions occur with beryllium, aluminum, titanium, zirconium, hafnium, and the rare earths lanthanum, cerium, praseodymium, and neodymium. The alkali metals tend to have the lowest enthalpies. These trends are essentially the same for all the oxidizers in the oxide, nitrate, and chlorate-perchlorate systems, and for the gravimetric and volumetric bases. Thus, all the curves are similar except for vertical displacement of the ordinates. This type of plot allows one to choose a metal reactant for a particular oxidizer, magnesium perchlorate in this case.

Table 21

DATA ON REACTIONS OF VARIOUS METALS WITH CHLORATES AND PERCHLORATES

	13 Mg	+ 4 $AgClO_3$	= 2 Ag_2Cl	+ 12 MgO	+ $MgCl_2$
Heat of formation		-5.73	-30.90	-143.84	-153.40
Molecular weight	24.32	191.34	251.20	40.32	95.23
Density	1.74	4.43		3.58	2.32
Melting point, °C	650.00	231.00		2800.00	714.00
Boiling point, °C	1120.00	270.00			1418.00
Heat of reaction, kcal	-1918.36				
Reactants' density	3.05				
Gravimetric enthalpy, cal/g	-1773.76				
Volumetric enthalpy, cal/cc	-5411.93				

	13 Mn	+ 4 $AgClO_3$	= 2 Ag_2Cl	+ 12 MnO	+ $MnCl_2$
Heat of formation		-5.73	-30.90	-92.00	-115.30
Molecular weight	54.94	191.34	251.20	70.93	125.84
Density	7.20	4.43		5.43	2.98
Melting point, °C	1244.00	231.00		1650.00	650.00
Boiling point, °C	2087.00	270.00			1190.00
Heat of reaction, kcal	-1258.18				
Reactants' density	5.44				
Gravimetric enthalpy, cal/g	-850.36				
Volumetric enthalpy, cal/cc	-4626.26				

	Mo +	$AgClO_3$	= AgCl	+ MoO_3
Heat of formation		-5.73	-30.36	-180.33
Molecular weight	95.95	191.34	143.34	143.95
Density	10.20	4.43	5.56	4.50
Melting point, °C	2610.00	231.00	455.00	795.00
Boiling point, °C	4800.00	270.00	1557.00	1155.00
Heat of reaction, kcal	-204.96			
Reactants' density	5.46			
Gravimetric enthalpy, cal/g	-713.43			
Volumetric enthalpy, cal/cc	-3896.71			

Table 21 (cont.)

	13 Zn	+ 4 $AgClO_3$	= 2 Ag_2Cl	+ 12 ZnO	+ $ZnCl_2$
Heat of formation		-5.73	-30.90	-83.17	-99.40
Molecular weight	65.38	191.34	251.20	81.38	136.29
Density	7.14	4.43		5.47	2.91
Melting point, °C	419.50	231.00		1800.00	275.00
Boiling point, °C	907.00	270.00		1800.00	756.00
Heat of reaction, kcal	-1136.32				
Reactants' density	5.54				
Gravimetric enthalpy, cal/g	-703.47				
Volumetric enthalpy, cal/cc	-3894.08				

	10 Zr	+ 6 $AgClO_3$	= 3 Ag_2Cl	+ 9 ZrO_2	+ $ZrCl_3$
Heat of formation		-5.73	-30.90	-258.20	-208.00
Molecular weight	91.22	191.34	251.20	123.22	197.59
Density	6.40	4.43		5.46	
Melting point, °C	1852.00	231.00		2700.00	350.00
Boiling point, °C	2900.00	270.00		4300.00	
Heat of reaction, kcal	-2590.12				
Reactants' density	5.13				
Gravimetric enthalpy, cal/g	-1257.10				
Volumetric enthalpy, cal/cc	-6448.18				

	16 Ag	+ 2 $AgClO_4$ =	8 Ag_2O	+ 2 AgCl
Heat of formation		-7.75	-7.31	-30.36
Molecular weight	107.87	207.34	231.76	143.34
Density	10.50	2.81	7.14	5.56
Melting point, °C	960.80	486.00	300.00	455.00
Boiling point, °C	2193.00			1557.00
Heat of reaction, kcal	-103.67			
Reactants' density	6.86			
Gravimetric enthalpy, cal/g	-48.43			
Volumetric enthalpy, cal/cc	-332.11			

Table 21 (cont.)

	2 Zr +	$LiClO_4$ =	LiCl +	2 ZrO_2	
Heat of formation		-106.10	-97.70	-258.20	
Molecular weight	91.22	106.50	42.40	123.22	
Density	6.40	2.43	2.07	5.46	
Melting point, °C	1852.00	236.00	610.00	2700.00	
Boiling point, °C	2900.00	440.00	1382.00	4300.00	
Heat of reaction, kcal	-508.00				
Reactants' density	3.99				
Gravimetric enthalpy, cal/g	-1758.15				
Volumetric enthalpy, cal/cc	-7021.28				
	8 Ag +	**$Mg(ClO_4)_2$ =**	**MgO_2 +**	**3 Ag_2O_2 +**	**2 AgCl**
Heat of formation		-140.60	-148.90	-6.30	-30.36
Molecular weight	107.87	223.23	56.32	247.76	143.34
Density	10.50	2.60		7.44	5.56
Melting point, °C	960.80	251.00		100.00	455.00
Boiling point, °C	2193.00				1557.00
Heat of reaction, kcal	-87.92				
Reactants' density	6.46				
Gravimetric enthalpy, cal/g	-80.95				
Volumetric enthalpy, cal/cc	-523.21				
	16 Al +	**3 $Mg(ClO_4)_2$ =**	**3 $MgCl_2$ +**	**8 Al_2O_3**	
Heat of formation		-140.60	-153.40	-399.09	
Molecular weight	26.98	223.23	95.23	101.94	
Density	2.70	2.60	2.32	3.97	
Melting point, °C	660.00	251.00	714.00	2015.00	
Boiling point, °C	2327.00		1418.00	3500.00	
Heat of reaction, kcal	-3231.12				
Reactants' density	2.64				
Gravimetric enthalpy, cal/g	-2933.73				
Volumetric enthalpy, cal/cc	-7742.25				

Table 21 (cont.)

	4 Ge	+	$Mg(ClO_4)_2$	=	$MgCl_2$	+	4 GeO_2
Heat of formation			-140.60		-153.40		-128.30
Molecular weight	72.60		223.23		95.23		104.60
Density	5.35		2.60		2.32		4.70
Melting point, °C	960.00		251.00		714.00		1000.00
Boiling point, °C	2700.00				1418.00		
Heat of reaction, kcal	-526.00						
Reactants' density	3.67						
Gravimetric enthalpy, cal/g	-1024.08						
Volumetric enthalpy, cal/cc	-3753.44						
	4 Hf	+	$Mg(ClO_4)_2$	=	$MgCl_2$	+	4 HfO_2
Heat of formation			-140.60		-153.40		-271.50
Molecular weight	178.50		223.23		95.23		210.60
Density	13.30		2.60		2.32		9.68
Melting point, °C	2227.00		251.00		714.00		2810.00
Boiling point, °C	3200.00				1418.00		
Heat of reaction, kcal	-1098.80						
Reactants' density	6.72						
Gravimetric enthalpy, cal/g	-1172.39						
Volumetric enthalpy, cal/cc	-7874.34						
	8 Hg	+	$Mg(ClO_4)_2$	=	$MgCl_2$	+	8 HgO
Heat of formation			-140.60		-153.40		-21.68
Molecular weight	200.61		223.23		95.23		216.61
Density	13.55		2.60		2.32		11.14
Melting point, °C	-38.87		251.00		714.00		500.00
Boiling point, °C	356.57				1418.00		
Heat of reaction, kcal	186.24						
Reactants' density	8.95						
Gravimetric enthalpy, cal/g	-101.88						
Volumetric enthalpy, cal/cc	-911.45						

Table 22

MOST ENERGETIC CHLORATE AND PERCHLORATE REACTIONS WITH METALS, IN TERMS OF VOLUMETRIC ENTHALPY

Reaction	Enthalpy, cal/cc
$8\ Be + Mg(ClO_4)_2 = MgCl_2 + 8\ BeO$	-9459
$4\ Be + Li(ClO_4) = LiCl + 4\ BeO$	-9088
$13\ Be + 4\ Ag(ClO_3) = 2\ Ag_2Cl + 12\ BeO + BeCl_2$	-8103
$4\ U + Mg(ClO_4)_2 = MgCl_2 + 4\ UO_2$	-7989
$4\ Hf + Mg(ClO_4)_2 = MgCl_2 + 4\ HfO_2$	-7874
$3\ Be + Na(ClO_3) = NaCl + 3\ BeO$	-7853
$4\ Be + K(ClO_4) = KCl + 4\ BeO$	-7850
$16\ Al + 3\ Mg(ClO_4)_2 = 3\ MgCl_2 + 8\ Al_2O_3$	-7742
$2\ U + Li(ClO_4) = LiCl + 2\ UO_2$	-7670
$2\ Hf + Li(ClO_4) = LiCl + 2\ HfO_2$	-7562
$8\ Al + 3\ Li(ClO_4) = 3\ LiCl + 4\ Al_2O_3$	-7431
$16\ B + 3\ Mg(ClO_4)_2 = 3\ MgCl_2 + 8\ B_2O_3$	-7423
$4\ Zr + Mg(ClO_4)_2 = MgCl_2 + 4\ ZrO_2$	-7318
$8\ Be + Ba(ClO_4)_2 = BaCl_2 + 8\ BeO$	-7302
$8\ B + 3\ Li(ClO_4) = 3\ LiCl + 4\ B_2O_3$	-7038
$2\ Zr + Li(ClO_4) = LiCl + 2\ ZrO_2$	-7021
$4\ Be + Rb(ClO_4) = RbCl + 4\ BeO$	-7002
$4\ Th + Mg(ClO_4)_2 = MgCl_2 + 4\ ThO_2$	-6998
$10\ U + 6\ Ag(ClO_3) = 3\ Ag_2Cl + 9\ UO_2 + UCl_3$	-6989
$16\ Ti + 3\ Mg(ClO_4)_2 = 3\ MgCl_2 + 8\ Ti_2O_3$	-6951
$13\ Hf + 8\ Ag(ClO_3) = 4\ Ag_2Cl + 12\ HfO_2 + HfCl_4$	-6905
$2\ Th + Li(ClO_4) = LiCl + 2\ ThO_2$	-6750
$3\ U + 2\ Na(ClO_3) = 2\ NaCl + 3\ UO_2$	-6750
$13\ Al + 6\ Ag(ClO_3) = 3\ Ag_2Cl + 6\ Al_2O_3 + AlCl_3$	-6733
$16\ Ta + 5\ Mg(ClO_4)_2 = 5\ MgCl_2 + 8\ Ta_2O_5$	-6730
$2\ U + K(ClO_4) = KCl + 2\ UO_2$	-6720
$3\ Hf + 2\ Na(ClO_3) = 2\ NaCl + 3\ HfO_2$	-6675
$8\ Ti + 3\ Li(ClO_4) = 3\ LiCl + 4\ Ti_2O_3$	-6658

Table 22 (cont.)

Reaction	Enthalpy, cal/cc
3 Be + $K(ClO_3)$ = KCl + 3 BeO	-6653
2 Hf + $K(ClO_4)$ = KCl + 2 HfO_2	-6643
3 Be + $Rb(ClO_3)$ = RbCl + 3 BeO	-6616
17 Be + 4 $Ag(ClO_4)$ = 2 Ag_2Cl + 16 BeO + $BeCl_2$	-6578
2 Al + $Na(ClO_3)$ = NaCl + Al_2O_3	-6562
4 Be + $Cs(ClO_4)$ = CsCl + 4 BeO	-6533
8 Al + 3 $K(ClO_4)$ = 3 KCl + 4 Al_2O_3	-6527
10 Zr + 6 $Ag(ClO_3)$ = 3 Ag_2Cl + 9 ZrO_2 + $ZrCl_3$	-6448
8 Ta + 5 $Li(ClO_4)$ = 5 LiCl + 4 Ta_2O_5	-6388
4 U + $Ba(ClO_4)_2$ = $BaCl_2$ + 4 UO_2	-6292
4 Si + $Mg(ClO_4)_2$ = $MgCl_2$ + 4 SiO_2	-6289
13 Th + 8 $Ag(ClO_3)$ = 4 Ag_2Cl + 12 ThO_2 + $ThCl_4$	-6289
16 Nb + 5 $Mg(ClO_4)_2$ = 5 $MgCl_2$ + 8 Nb_2O_5	-6249
2 B + $Ag(ClO_3)$ = AgCl + B_2O_3	-6242
3 Zr + 2 $Na(ClO_3)$ = 2 NaCl + 3 ZrO_2	-6234
4 Hf + $Ba(ClO_4)_2$ = $BaCl_2$ + 4 HfO_2	-6228
2 Zr + $K(ClO_4)$ = KCl + 2 ZrO_2	-6192
16 Al + 3 $Ba(ClO_4)_2$ = 3 $BaCl_2$ + 8 Al_2O_3	-6119
3 Th + 2 $Na(ClO_3)$ = 2 NaCl + 3 ThO_2	-6102
13 Ti + 6 $Ag(ClO_3)$ = 3 Ag_2Cl + 6 Ti_2O_3 + $TiCl_3$	-6100
16 Sc + 3 $Mg(ClO_4)_2$ = 3 $MgCl_2$ + 8 Sc_2O_3	-6099
2 Th + $K(ClO_4)$ = KCl + 2 ThO_2	-6063
2 B + $Na(ClO_3)$ = NaCl + B_2O_3	-6061
2 U + $Rb(ClO_4)$ = RbCl + 2 UO_2	-6040
16 Nd + 3 $Mg(ClO_4)_2$ = 3 $MgCl_2$ + 8 Nd_2O_3	-6036
8 B + 3 $K(ClO_4)$ = 3 KCl + 4 B_2O_3	-6004
2 Si + $Li(ClO_4)$ = LiCl + 2 SiO_2	-5983
16 La + 3 $Mg(ClO_4)_2$ = 3 $MgCl_2$ + 8 La_2O_3	-5981
2 Hf + $Rb(ClO_4)$ = RbCl + 2 HfO_2	-5981
16 V + 3 $Mg(ClO_4)_2$ = 3 $MgCl_2$ + 8 V_2O_3	5980

Table 22 (cont.)

Reaction	Enthalpy, cal/cc
$16\ Pr + 3\ Mg(ClO_4)_2 = 3\ MgCl_2 + 8\ Pr_2O_3$	-5946
$16\ Ce + 3\ Mg(ClO_4)_2 = 3\ MgCl_2 + 8\ Ce_2O_3$	-5941
$2\ Ti + Na(ClO_3) = NaCl + Ti_2O_3$	-5926
$8\ Nb + 5\ Li(ClO_4) = 5\ LiCl + 4\ Nb_2O_5$	-5914
$8\ Mg + Mg(ClO_4)_2 = MgCl_2 + 8\ MgO$	-5886
$16\ Cr + 3\ Mg(ClO_4)_2 = 3\ MgCl_2 + 8\ Cr_2O_3$	-5885
$8\ Sc + 3\ Li(ClO_4) = 3\ LiCl + 4\ Sc_2O_3$	-5877
$8\ Ti + 3\ K(ClO_4) = 3\ KCl + 4\ Ti_2O_3$	-5876
$8\ Al + 3\ Rb(ClO_4) = 3\ RbCl + 4\ Al_2O_3$	-5875
$8\ Nd + 3\ Li(ClO_4) = 3\ LiCl + 4\ Nd_2O_3$	-5832
$4\ Zr + Ba(ClO_4)_2 = BaCl_2 + 4\ ZrO_2$	-5817
$8\ La + 3\ Li(ClO_4) = 3\ LiCl + 4\ La_2O_3$	-5786
$3\ U + 2\ K(ClO_3) = 2\ KCl + 3\ UO_2$	-5779
$6\ Ta + 5\ Ag(ClO_3) = 5\ AgCl + 3\ Ta_2O_5$	-5767
$8\ Pr + 3\ Li(ClO_4) = 3\ LiCl + 4\ Pr_2O_3$	-5747
$3\ U + 2\ Rb(ClO_3) = 2\ RbCl + 3\ UO_2$	-5747
$13\ U + 6\ Ag(ClO_4) = 3\ Ag_2Cl + 12\ UO_2 + UCl_3$	-5747
$4\ Th + Ba(ClO_4)_2 = BaCl_2 + 4\ ThO_2$	-5743
$8\ Ce + 3\ Li(ClO_4) = 3\ LiCl + 4\ Ce_2O_3$	-5737
$3\ Hf + 2\ K(ClO_3) = 2\ KCl + 3\ HfO_2$	-5728
$3\ Hf + 2\ Rb(ClO_3) = 2\ RbCl + 3\ HfO_2$	-5696
$17\ Hf + 8\ Ag(ClO_4) = 4\ Ag_2Cl + 16\ HfO_2 + HfCl_4$	-5688
$4\ Mg + Li(ClO_4) = LiCl + 4\ MgO$	-5683
$8\ V + 3\ Li(ClO_4) = 3\ LiCl + 4\ V_2O_3$	-5676
$2\ U + Cs(ClO_4) = CsCl + 2\ UO_2$	-5662
$2\ Al + K(ClO_3) = KCl + Al_2O_3$	-5629
$2\ Hf + Cs(ClO_4 = CsCl + 2\ HfO_2$	-5612
$2\ Al + Rb(ClO_3) = RbCl + Al_2O_3$	-5597
$6\ Ta + 5\ Na(ClO_3) = 5\ NaCl + 3\ Ta_2O_5$	-5596
$16\ Zr + 8\ Rb(ClO_4) = 8\ RbCl + 16\ ZrO_2$	-5585

Table 22 (cont.)

Reaction	Enthalpy, cal/cc
$13\ Nd + 6\ Ag(ClO_3) = 3\ Ag_2Cl + 6\ Nd_2O_3 + NdCl_3$	-5583
$13\ Sc + 6\ Ag(ClO_3) = 3\ Ag_2Cl + 6\ Sc_2O_3 + ScCl_3$	-5568
$8\ Cr + 3\ Li(ClO_4) = 3\ LiCl + 4\ Cr_2O_3$	-5565
$16\ B + 3\ Ba(ClO)_4 = 3\ BaCl_2 + 8\ B_2O_3$	-5562
$13\ La + 6\ Ag(ClO_3) = 3\ Ag_2Cl + 6\ La_2O_3 + LaCl_3$	-5553
$17\ Al + 6\ Ag(ClO_4) = 3\ Ag_2Cl + 8\ Al_2O_3 + AlCl_3$	-5553
$2\ Th + Rb(ClO_4) = RbCl + 2\ ThO_2$	-5542
$8\ Ta + 5\ K(ClO_4) = 5\ KCl + 4\ Ta_2O_5$	-5530
$16\ Ti + 3\ Ba(ClO_4)_2 = 3\ BaCl_2 + 8\ Ti_2O_3$	-5523
$13\ Ce + 6\ Ag(ClO_3) = 3\ Ag_2Cl + 6\ Ce_2O_3 + CeCl_3$	-5514
$13\ Pr + 6\ Ag(ClO_3) = 3\ Ag_2Cl + 6\ Pr_2O_3 + PrCl_3$	-5514
$8\ Al + 3\ Cs(ClO_4) = 3\ CsCl + 4\ Al_2O_3$	-5512
$3\ Si + 2\ Ag(ClO_3) = 2\ AgCl + 3\ SiO_2$	-5477
$13\ Mg + 4\ Ag(ClO_3) = 2\ Ag_2Cl + 12\ MgO + MgCl_2$	-5411
$6\ Nb + 5\ Ag(ClO_3) = 5\ AgCl + 3\ Nb_2O_5$	-5380
$2\ Sc + Na(ClO_3) = NaCl + Sc_2O_3$	-5379
$2\ Nd + Na(ClO_3) = NaCl + Nd_2O_3$	-5374
$3\ Zr + 2\ K(ClO_3) = 2\ KCl + 3\ ZrO_2$	-5363
$2\ La + Na(ClO_3) = NaCl + La_2O_3$	-5350
$3\ Th + 2\ K(ClO_3) = 2\ KCl + 3\ ThO_2$	-5348
$13\ Zr + 6\ Ag(ClO_4) = 3\ Ag_2Cl + 12\ ZrO_2 + ZrCl_3$	-5333
$3\ Zr + 2\ Rb(ClO_3) = 2\ RbCl + 3\ ZrO_2$	-5332
$8\ Sc + 3\ K(ClO_4) = 3\ KCl + 4\ Sc_2O_3$	-5329
$8\ Nd + 3\ K(ClO_4) = 3\ KCl + 4\ Nd_2O_3$	-5327
$3\ Th + 2\ Rb(ClO_3) = 2\ RbCl + 3\ ThO_2$	-5320
$17\ Th + 8\ Ag(ClO_4) = 4\ Ag_2Cl + 16\ ThO_2 + ThCl_4$	-5320
$3\ Si + 2\ Na(ClO_3) = 2\ NaCl + 3\ SiO_2$	-5316
$2\ Pr + Na(ClO_3) = NaCl + Pr_2O_3$	-5307
$8\ La + 3\ K(ClO_4) = 3\ KCl + 4\ La_2O_3$	-5305
$8\ Ti + 3\ Rb(ClO_4) = 3\ RbCl + 4\ Ti_2O_3$	-5299

Table 22 (cont.)

Reaction	Enthalpy, cal/cc
2 Ce + $Na(ClO_3)$ = NaCl + Ce_2O_3	-5290
8 B + 3 $Rb(ClO_4)$ = 3 RbCl + 4 B_2O_3	-5289
8 Pr + 3 $K(ClO_4)$ = 3 KCl + 4 Pr_2O_3	-5259
2 Si + $K(ClO_4)$ = KCl + 2 SiO_2	-5247
2 Zr + $Cs(ClO_4)$ = CsCl + 2 ZrO_2	-5246
2 Th + $Cs(ClO_4)$ = CsCl + 2 ThO_2	-5245
3 Mg + $Na(ClO_3)$ = NaCl + 3 MgO	-5243
8 Ce + 3 $K(ClO_4)$ = 3 KCl + 4 Ce_2O_3	-5242
9 V + 4 $Ag(ClO_3)$ = 2 Ag_2Cl + 4 V_2O_3 + VCl_2	-5233
6 Nb + 5 $Na(ClO_3)$ = 5 NaCl + 3 Nb_2O_5	-5205
4 Mg + $K(ClO_4)$ = KCl + 4 MgO	-5193
16 Ta + 5 $Ba(ClO_4)_2$ = 5 $BaCl_2$ + 8 Ta_2O_5	-5155
6 Mn + $Mg(ClO_4)_2$ = $MgCl_2$ + 2 Mn_3O_4	-5132
13 Cr + 6 $Ag(ClO_3$ = 3 Ag_2Cl + 6 Cr_2O_3 + $CrCl_3$	-5129
8 Nb + 5 $K(ClO_4)$ = 5 KCl + 4 Nb_2O_5	-5128
2 Ti + $K(ClO_3)$ = KCl + Ti_2O_3	-5095
16 Nd + 3 $Ba(ClO_4)_2$ = 3 $BaCl_2$ + 8 Nd_2O_3	-5086
16 La + 3 $Ba(ClO_4)_2$ = 3 $BaCl_2$ + 8 La_2O_3	-5074
16 Sc + 3 $Ba(ClO_4)_2$ = 3 $BaCl_2$ + 8 Sc_2O_3	-5071
2 Ti + $Rb(ClO_3)$ = RbCl + Ti_2O_3	-5065
2 V + $Na(ClO_3)$ = NaCl + V_2O_3	-5054
2 B + $K(ClO_3)$ = KCl + B_2O_3	-5046
17 Ti + 6 $Ag(ClO_4)$ = 3 Ag_2Cl + 8 Ti_2O_3 + $TiCl_3$	-5041
16 Pr + 3 $Ba(ClO_4)_2$ = 3 $BaCl_2$ + 8 Pr_2O_3	-5026
2 B + $Rb(ClO_3)$ = RbCl + B_2O_3	-5010
16 Ce + 3 $Ba(ClO_4)_2$ = 3 $BaCl_2$ + 8 Ce_2O_3	-5005
8 V + 3 $K(ClO_4)$ = 3 KCl + 4 V_2O_3	-4978
8 Ti + 3 $Cs(ClO_4)$ = 3 CsCl + 4 Ti_2O_3	-4977
8 Mg + $Ba(ClO_4)_2$ = $BaCl_2$ + 8 MgO	-4960
8 B + 3 $Ag(ClO_4)$ = 3 AgCl + 4 B_2O_3	-4941

Table 22 (cont.)

Reaction	Enthalpy, cal/cc
$2\,Cr + Na(ClO_3) = NaCl + Cr_2O_3$	-4933
$8\,W + 3\,Mg(ClO_4)_2 = 3\,MgCl_2 + 8\,WO_3$	-4923
$8\,Nd + 3\,Rb(ClO_4) = 3\,RbCl + 4\,Nd_2O_3$	-4922
$4\,Si + Ba(ClO_4)_2 = BaCl_2 + 4\,SiO_2$	-4921
$8\,La + 3\,Rb(ClO_4) = 3\,RbCl + 4\,La_2O_3$	-4916
$8\,Ta + 5\,Rb(ClO_4) = 5\,RbCl + 4\,Ta_2O_5$	-4912
$8\,B + 3\,Cs(ClO_4) = 3\,CsCl + 4\,B_2O_3$	-4905
$8\,Sc + 3\,Rb(ClO_4) = 3\,RbCl + 4\,Sc_2O_3$	-4896
$8\,Pr + 3\,Rb(ClO_4) = 3\,RbCl + 4\,Pr_2O_3$	-4866
$8\,Cr + 3\,K(ClO_4) = 3\,KCl + 4\,Cr_2O_3$	-4851
$8\,Ce + 3\,Rb(ClO_4) = 3\,RbCl + 4\,Ce_2O_3$	-4843
$3\,Mn + Li(ClO_4) = LiCl + Mn_3O_4$	-4839
$17\,La + 6\,Ag(ClO_4) = 3\,Ag_2Cl + 8\,La_2O_3 + LaCl_3$	-4803
$17\,Nd + 6\,Ag(ClO_4) = 3\,Ag_2Cl + 8\,Nd_2O_3$	-4802
$4\,Mg + Rb(ClO_4) = RbCl + 4\,MgO$	-4799
$16\,Nb + 5\,Ba(ClO_4)_2 = 5\,BaCl_2 + 8\,Nb_2O_5$	-4786
$2\,Nd + K(ClO_3) = KCl + Nd_2O_3$	-4783
$2\,La + K(ClO_3) = KCl + La_2O_3$	-4782
$2\,La + Rb(ClO_3) = RbCl + La_2O_3$	-4759
$2\,Nd + Rb(ClO_3) = RbCl + Nd_2O_3$	-4759
$17\,Pr + 6\,Ag(ClO_4) = 3\,Ag_2Cl + 8\,Pr_2O_3 + PrCl_3$	-4854
$2\,Sc + K(ClO_3) = KCl + Sc_2O_3$	-4749
$17\,Sc + 6\,Ag(ClO_4) = 3\,Ag_2Cl + 8\,Sc_2O_3 + ScCl_3$	-4745
$17\,Ce + 6\,Ag(ClO_4) = 3\,Ag_2Cl + 8\,Ce_2O_3 + CeCl_3$	-4739
$2\,Pr + K(ClO_3) = KCl + Pr_2O_3$	-4732
$2\,Sc + Rb(ClO_3) = RbCl + Sc_2O_3$	-4724
$6\,Ta + 5\,K(ClO_3) = 5\,KCl + 3\,Ta_2O_5$	-4713
$2\,Pr + Rb(ClO_3) = RbCl + Pr_2O_3$	-4709
$16\,Ga + 3\,Mg(ClO_4)_2 = 3\,MgCl_2 + 8\,Ga_2O_3$	-4708
$2\,Ce + K(ClO_3) = KCl + Ce_2O_3$	-4708
$2\,Si + Rb(ClO_4) = RbCl + 2\,SiO_2$	-4701

Table 22 (cont.)

Reaction	Enthalpy, cal/cc
8 La + 3 $Cs(ClO_4)$ = 3 CsCl + 4 La_2O_3	-4691
8 Nd + 3 $Cs(ClO_4)$ = 3 CsCl + 4 Nd_2O_3	-4689
2 Ce + $Rb(ClO_3)$ = RbCl + Ce_2O_3	-4685
6 Ta + 5 $Rb(ClO_3)$ = 5 RbCl + 3 Ta_2O_5	-4679
16 V + 3 $Ba(ClO_4)_2$ = 3 $BaCl_2$ + 8 V_2O_3	-4670
3 Mg + $K(ClO_3)$ = KCl + 3 MgO	-4666
17 Mg + 4 $Ag(ClO_4)$ = 2 Ag_2Cl + 16 MgO + $MgCl_2$	-4661
8 Sc + 3 $Cs(ClO_4)$ = 3 CsCl + 4 Sc_2O_3	-4648
3 Mg + $Rb(ClO_3)$ = RbCl + 3 MgO	-4643
8 Pr + 3 $Cs(ClO_4)$ = 3 CsCl + 4 Pr_2O_3	-4639
13 Mn + 4 $Ag(ClO_3)$ = 2 Ag_2Cl + 12 MnO + $MnCl_2$	-4626
8 Ta + 5 $Ag(ClO_4)$ = 5 AgCl + 4 Ta_2O_5	-4626
8 Ce + 3 $Cs(ClO_4)$ = 3 CsCl + 4 Ce_2O_3	-4614
4 W + 3 $Li(ClO_4)$ = 3 LiCl + 4 WO_3	-4587
8 Ta + 5 $Cs(ClO_4)$ = 5 CsCl + 4 Ta_2O_5	-4577
4 Mg + $Cs(ClO_4)$ = CsCl + 4 MgO	-4572
8 Nb + 5 $Rb(ClO_4)$ = 5 RbCl + 4 Nb_2O_5	-4554
16 Cr + 3 $Ba(ClO_4)_2$ = 3 $BaCl_2$ + 8 Cr_2O_3	-4539
3 Si + 2 $K(ClO_3)$ = 2 KCl + 3 SiO_2	-4529
3 Si + 2 $Rb(ClO_3)$ = 2 RbCl + 3 SiO_2	-4498
8 V + 3 $Rb(ClO_4)$ = 3 RbCl + 4 V_2O_3	-4455
8 Ga + 3 $Li(ClO_4)$ = 3 LiCl + 4 Ga_2O_3	-4454
2 Si + $Ag(ClO_4)$ = AgCl + 2 SiO_2	-4454
8 Mo + 3 $Mg(ClO_4)_2$ = 3 $MgCl_2$ + 8 MoO_3	-4449

Table 23

MOST ENERGETIC CHLORATE AND PERCHLORATE REACTIONS WITH METALS, IN TERMS OF GRAVIMETRIC ENTHALPY

Reaction	Enthalpy, cal/g
$4\,Be + Li(ClO_4) = LiCl + 4\,BeO$	-4037
$8\,Be + Mg(ClO_4)_2 = MgCl_2 + 8\,BeO$	-3998
$16\,Li + Mg(ClO_4)_2 = MgO + 7\,Li_2O + 2\,LiCl$	-3576
$8\,Li + Li(ClO_4) = LiCl + 4\,Li_2O$	-3463
$3\,Be + Na(ClO_3) = NaCl + 3\,BeO$	-3374
$4\,Be + K(ClO_4) = KCl + 4\,BeO$	-3348
$34\,Li + 2\,Cu(ClO_4)_2 = Cu_2O + 15\,Li_2O + 4\,LiCl$	-3323
$12\,Li + 2\,Li(ClO_3) = Li_2O + 5\,Li_2O + 2\,LiCl$	-3310
$16\,Li + 2\,Na(ClO_4) = Na_2O + 7\,Li_2O + 2\,LiCl$	-3110
$26\,Li + 2\,Cu(ClO_3)_2 = Cu_2O + 11\,Li_2O + 4\,LiCl$	-3015
$3\,Be + K(ClO_3) = KCl + 3\,BeO$	-2999
$6\,Li + Na(ClO_3) = NaCl + 3\,Li_2O$	-2969
$8\,Li + K(ClO_4) = KCl + 4\,Li_2O$	-2937
$8\,Al + 3\,Li(ClO_4) = 3\,LiCl + 4\,Al_2O_3$	-2934
$16\,Al + 3\,Mg(ClO_4)_2 = 3\,MgCl_2 + 8\,Al_2O_3$	-2933
$8\,B + 3\,Li(ClO_4) = 3\,LiCl + 4\,B_2O_3$	-2912
$16\,B + 3\,Mg(ClO_4)_2 = 3\,MgCl_2 + 8\,B_2O_3$	-2912
$8\,Be + Ba(ClO_4)_2 = BaCl_2 + 8\,BeO$	-2891
$8\,Mg + Mg(ClO_4)_2 = MgCl_2 + 8\,MgO$	-2784
$4\,Mg + Li(ClO_4) = LiCl + 4\,MgO$	-2782
$6\,Li + K(ClO_3) = KCl + 3\,Li_2O$	-2666
$4\,Be + Rb(ClO_4) = RbCl + 4\,BeO$	-2638
$16\,Li + Ba(ClO_4)_2 = BaCl_2 + 8\,Li_2O$	-2575
$2\,Al + Na(ClO_3) = NaCl + Al_2O_3$	-2565
$17\,Be + 4\,Ag(ClO_4) = 2\,Ag_2Cl + 16\,BeO + BeCl_2$	-2533
$8\,Al + 3\,K(ClO_4) = 3\,KCl + 4\,Al_2O_3$	-2530
$4\,Si + Mg(ClO_4)_2 = MgCl_2 + 4\,SiO_2$	-2486
$3\,Mg + Na(ClO_3) = NaCl + 3\,MgO$	-2474
$2\,Si + Li(ClO_4) = LiCl + 2\,SiO_2$	-2473

Table 23 (cont.)

Reaction	Enthalpy, cal/g
$2\,B + Na(ClO_3) = NaCl + B_2O_3$	-2455
$4\,Mg + K(ClO_4) = KCl + 4\,MgO$	-2442
$8\,B + 3\,K(ClO_4) = 3\,KCl + 4\,B_2O_3$	-2408
$16\,Sc + 3\,Mg(ClO_4)_2 = 3\,MgCl_2 + 8\,Sc_2O_3$	-2394
$8\,Sc + 3\,Li(ClO_4) = 3\,LiCl + 4\,Sc_2O_3$	-2383
$8\,Li + Rb(ClO_4) = RbCl + 4\,Li_2O$	-2364
$17\,Li + 2\,Ag(ClO_4) = Ag_2Cl + 8\,Li_2O + LiCl$	-2351
$2\,Al + K(ClO_3) = KCl + Al_2O_3$	-2321
$3\,Be + Rb(ClO_3) = RbCl + 3\,BeO$	-2281
$3\,Mg + K(ClO_3) = KCl + 3\,MgO$	-2261
$8\,Ca + Mg(ClO_4)_2 = MgCl_2 + 8\,CaO$	-2257
$4\,Ca + Li(ClO_4) = LiCl + 4\,CaO$	-2245
$16\,Al + 3\,Ba(ClO_4)_2 = 3\,BaCl_2 + 8\,Al_2O_3$	-2242
$14\,Al + 2\,Cu(ClO_4)_2 = Cu_2O + 5\,Al_2O_3 + 4\,AlCl$	-2234
$12\,Li + Ba(ClO_3)_2 = BaO + 5\,Li_2O + 2\,LiCl$	-2217
$8\,Mg + Ba(ClO_4)_2 = BaCl_2 + 8\,MgO$	-2191
$4\,Be + Cs(ClO_4) = CsCl + 4\,BeO$	-2174
$2\,B + K(ClO_3) = KCl + B_2O_3$	-2168
$13\,Be + 4\,Ag(ClO_3) = 2\,Ag_2Cl + 12\,BeO + BeCl_2$	-2167
$3\,Si + 2\,Na(ClO_3) = 2\,NaCl + 3\,SiO_2$	-2157
$2\,Sc + Na(ClO_3) = NaCl + Sc_2O_3$	-2156
$8\,Sc + 3\,K(ClO_4) = 3\,KCl + 4\,Sc_2O_3$	-2122
$2\,Si + K(ClO_4) = KCl + 2\,SiO_2$	-2112
$14\,B + 2\,Cu(ClO_4)_2 = Cu_2O + 5\,B_2O_3$	-2083
$16\,B + 3\,Ba(ClO_4)_2 = 5\,BaCl_2 + 8\,B_2O_3$	-2076
$16\,Ti + 3\,Mg(ClO_4)_2 = 3\,MgCl_2 + 8\,Ti_2O_3$	-2071
$6\,Li + Rb(ClO_3) = RbCl + 3\,Li_2O$	-2071
$8\,Al + 3\,Rb(ClO_4) = 3\,RbCl + 4\,Al_2O_3$	-2067
$3\,Ca + Na(ClO_3) = NaCl + 3\,CaO$	-2065
$13\,Li + 2\,Ag(ClO_3) = Ag_2Cl + 6\,Li_2O + 1\,LiCl$	-2054
$8\,Ti + 3\,Li(ClO_4) = 3\,LiCl + 4\,Ti_2O_3$	-2053

Table 23 (cont.)

Reaction	Enthalpy, cal/g
$4\ Mg + Rb(ClO_4) = RbCl + 4\ MgO$	-2035
$4\ Ca + K(ClO_4) = KCl + 4\ CaO$	-2034
$20\ Al + 6\ Na(ClO_4) = 3\ Na_2O + 7\ Al_2O_3 + 6\ AlCl$	-2015
$17\ Mg + 4\ Ag(ClO_4) = 2\ Ag_2Cl + 16\ MgO + MgCl_2$	-2000
$17\ Al + 6\ Ag(ClO_4) = 3\ Ag_2Cl + 8\ Al_2O_3 + AlCl_3$	-1999
$2\ Sc + K(ClO_3) = KCl + Sc_2O_3$	-1984
$34\ Be + 4\ Cu(ClO_4)_2 = 2\ Cu_2O + 15\ BeO + 4\ BeCl_2$	-1978
$16\ Al + 6\ Li(ClO_3) = 3\ Li_2O + 5\ Al_2O_3 + 6\ AlCl$	-1977
$8\ Li + Cs(ClO_4) = CsCl + 4\ Li_2O$	-1977
$12\ Be + 4\ Li(ClO_3) = 2\ Li_2O + 5\ BeO + 2\ BeCl_2$	-1935
$3\ Si + 2\ K(ClO_3) = 2\ KCl + 3\ SiO_2$	-1935
$16\ Sc + 3\ Ba(ClO_4)_2 = 3\ BaCl_2 + 8\ Sc_2O_3$	-1924
$3\ Ca + K(ClO_3) = KCl + 3\ CaO$	-1920
$34\ Al + 6\ Cu(ClO_3)_2 = 3\ Cu_2O + 11\ Al_2O_3 + 12\ AlCl$	-1903
$8\ B + 3\ Rb(ClO_4) = 3\ RbCl + 4\ B_2O_3$	-1878
$2\ Ti + Na(ClO_3) = NaCl + Ti_2O_3$	-1876
$8\ Ca + Ba(ClO_4)_2 = BaCl_2 + 8\ CaO$	-1869
$4\ Si + Ba(ClO_4)_2 = BaCl_2 + 4\ SiO_2$	-1859
$8\ Ti + 3\ K(ClO_4) = 3\ KCl + 4\ Ti_2O_3$	-1839
$2\ Al + Rb(ClO_3) = RbCl + Al_2O_3$	-1831
$3\ Mg + Rb(ClO_3) = RbCl + 3\ MgO$	-1821
$8\ B + 3\ Ag(ClO_4) = 3\ AgCl + 4\ B_2O_3$	-1800
$8\ Sc + 3\ Rb(ClO_4) = 3\ RbCl + 4\ Sc_2O_3$	-1794
$20\ B + 6\ Na(ClO_4) = 3\ Na_2O + 7\ B_2O_3 + 6\ BCl$	-1793
$4\ Zr + Mg(ClO_4)_2 = MgCl_2 + 4\ ZrO_2$	-1777
$13\ Mg + 4\ Ag(ClO_3) = 2\ Ag_2Cl + 12\ MgO + MgCl_2$	-1773
$26\ Be + 4\ Cu(ClO_3)_2 = 2\ Cu_2O + 11\ BeO + 4\ BeCl_2$	-1771
$17\ Sc + 6\ Ag(ClO_4) = 3\ Ag_2Cl + 8\ Sc_2O_3 + Sc_2O_3$	-1770
$16\ B + 6\ Li(ClO_3) = 3\ Li_2O + 5\ B_2O_3 + 6\ BCl$	-1758
$2\ Zr + Li(ClO_4) = LiCl + 2\ ZrO_2$	-1758
$4\ Ca + Rb(ClO_4) = RbCl + 4\ CaO$	-1757

Table 23 (cont.)

Reaction	Enthalpy, cal/g
$17\,Ca + 4\,Ag(ClO_4) = 2\,Ag_2Cl + 16\,CaO + CaCl_2$	-1754
$13\,Al + 6\,Ag(ClO_3) = 3\,Ag_2Cl + 6\,Al_2O_3 + AlCl_3$	-1747
$8\,Al + 3\,Cs(ClO_4) = 3\,CsCl + 4\,Al_2O_3$	-1747
$4\,Mg + Cs(ClO_4) = CsCl + 4\,MgO$	-1744
$16\,Be + 4\,Na(ClO_4) = 2\,Na_2O + 7\,BeO + 2\,BeCl_2$	-1729
$2\,Ti + K(ClO_3) = KCl + Ti_2O_3$	-1729
$2\,Si + Rb(ClO_4) = RbCl + 2\,SiO_2$	-1699
$34\,B + 6\,Cu(ClO_3)_2 = 3\,Cu_2O + 11\,B_2O_3 + 12\,BCl$	-1682
$16\,Ti + 3\,Ba(ClO_4)_2 = 3\,BaCl_2 + 8\,Ti_2O_3$	-1675
$2\,Si + Ag(ClO_4) = AgCl + 2\,SiO_2$	-1644
$3\,Zr + 2\,Na(ClO_3) = 2\,NaCl + 3\,ZrO_2$	-1643
$2\,B + Rb(ClO_3) = RbCl + B_2O_3$	-1632
$2\,Sc + Rb(ClO_3) = RbCl + Sc_2O_3$	-1622
$2\,Zr + K(ClO_4) = KCl + 2\,ZrO_2$	-1610
$3\,Ca + Rb(ClO_3) = RbCl + 3\,CaO$	-1607
$13\,Ca + 4\,Ag(ClO_3) = 2\,Ag_2Cl + 12\,CaO + CaCl_2$	-1594
$16\,V + 3\,Mg(ClO_4)_2 = 3\,MgCl_2 + 8\,V_2O_3$	-1588
$13\,Sc + 6\,Ag(ClO_3) = 3\,Ag_2Cl + 6\,Sc_2O_3 + ScCl_3$	-1584
$8\,Ti + 3\,Rb(ClO_4) = 3\,RbCl + 4\,Ti_2O_3$	-1561
$8\,V + 3\,Li(ClO_4) = 3\,LiCl + 4\,V_2O_3$	-1560
$8\,Sc + 3\,Cs(ClO_4) = 3\,CsCl + 4\,Sc_2O_3$	-1554
$4\,Ca + Cs(ClO_4) = CsCl + 4\,CaO$	-1546
$8\,B + 3\,Cs(ClO_4) = 3\,CsCl + 4\,B_2O_3$	-1540
$3\,Zr + 2\,K(ClO_3) = 2\,KCl + 3\,ZrO_2$	-1534
$2\,B + Ag(ClO_3) = AgCl + B_2O_3$	-1533
$17\,Ti + 6\,Ag(ClO_4) = 3\,Ag_2Cl + 8\,Ti_2O_3 + TiCl_3$	-1528
$3\,Si + 2\,Rb(ClO_3) = 2\,RbCl + 3\,SiO_2$	-1502
$4\,Zr + Ba(ClO_4)_2 = BaCl_2 + 4\,ZrO_2$	-1491
$34\,Mg + 4\,Cu(ClO_4)_2 = 2\,Cu_2O + 30\,MgO + 4\,MgCl_2$	-1478
$12\,Mg + 4\,Li(ClO_3) = 2\,Li_2O + 10\,MgO + 2\,MgCl_2$	-1470

Table 23 (cont.)

Reaction	Enthalpy, cal/g
$16\ Cr + 3\ Mg(ClO_4)_2 = 3\ MgCl_2 + 8\ Cr_2O_3$	-1462
$2\ V + Na(ClO_3) = NaCl + V_2O_3$	-1451
$16\ Nb + 5\ Mg(ClO_4)_2 = 5\ MgCl_2 + 8\ Nb_2O_5$	-1448
$12\ Na + 2\ Li(ClO_3) = Li_2O + 5\ Na_2O + 2\ NaCl$	-1446
$18\ Na + 2\ Mg(ClO_4)_2 = 2\ MgO + 7\ Na_2O_2 + 4\ NaCl$	-1445
$34\ Na + 2\ Cu(ClO_4)_2 = Cu_2O + 15\ Na_2O + 4\ NaCl$	-1443
$4\ C + Mg(ClO_4)_2 = MgCl_2 + 4\ CO_2$	-1433
$8\ Cr + 3\ Li(ClO_4) = 3\ LiCl + 4\ Cr_2O_3$	-1432
$3\ Si + 2\ Ag(ClO_3) = 2\ AgCl + 3\ SiO_2$	-1425
$2\ Si + Cs(ClO_4) = CsCl + 2\ SiO_2$	-1422
$2\ Ti + Rb(ClO_3) = RbCl + Ti_2O_3$	-1420
$8\ Nb + 5\ Li(ClO_4) = 5\ LiCl + 4\ Nb_2O_5$	-1419
$8\ V + 3\ K(ClO_4) = 3\ KCl + 4\ V_2O_3$	-1411
$16\ Zr + 8\ Rb(ClO_4) = 8\ RbCl + 16\ ZrO_2$	-1403
$16\ Al + 3\ Ba(ClO_3)_2 = 3\ BaO + 5\ Al_2O_3 + 6\ AlCl$	-1398
$26\ Mg + 4\ Cu(ClO_3)_2 = 2\ Cu_2O + 22\ MgO + 4\ MgCl_2$	-1382
$26\ Na + 2\ Cu(ClO_3)_2 = Cu_2O + 11\ Na_2O + 4\ NaCl$	-1381
$13\ Zr + 6\ Ag(ClO_4) = 3\ Ag_2Cl + 12\ ZrO_2 + ZrCl_3$	-1379
$2\ C + Li(ClO_4) = LiCl + 2\ CO_2$	-1376
$13\ Ti + 6\ Ag(ClO_3) = 3\ Ag_2Cl + 6\ Ti_2O_3 + TiCl_3$	-1369
$8\ Ti + 3\ Cs(ClO_4) = 3\ CsCl + 4\ Ti_2O_3$	-1357
$2\ Cr + Na(ClO_3) = NaCl + Cr_2O_3$	-1340
$2\ V + K(ClO_3) = KCl + V_2O_3$	-1339
$6\ Nb + 5\ Na(ClO_3) = 5\ NaCl + 3\ Nb_2O_5$	-1332
$16\ Na + 2\ Na(ClO_4) = Na_2O + 7\ Na_2O + 2\ NaCl$	-1317
$18\ Na + 4\ Li(ClO_4) = 2\ Li_2O + 7\ Na_2O_2 + 4\ NaCl$	-1306
$16\ Mg + 4\ Na(ClO_4) = 2\ Na_2O + 14\ MgO + 2\ MgCl_2$	-1301
$8\ Cr + 3\ K(ClO_4) = 3\ KCl + 4\ Cr_2O_3$	-1299
$3\ Zr + 2\ Rb(ClO_3) = 2\ RbCl + 3\ ZrO_2$	-1296
$8\ Nb + 5\ K(ClO_4) = 5\ KCl + 4\ Nb_2O_5$	-1292

Table 23 (cont.)

Reaction	Enthalpy, cal/g
$16 V + 3 Ba(ClO_4)_2 = 3 BaCl_2 + 8 V_2O_3$	-1292
$16 La + 3 Mg(ClO_4)_2 = 3 MgCl_2 + 8 La_2O_3$	-1280
$12 Ca + 4 Li(ClO_3) = 2 Li_2O + 10 CaO + 2 CaCl_2$	-1274
$8 La + 3 Li(ClO_4) = 3 LiCl + 4 La_2O_3$	-1262
$34 Ca + 4 Cu(ClO_4)_2 = 2 Cu_2O + 30 CaO + 4 CaCl_2$	-1260
$10 Zr + 6 Ag(ClO_3) = 3 Ag_2Cl + 9 ZrO_2 + ZrCl_3$	-1257
$2 Zr + Cs(ClO_4) = CsCl + 2 ZrO_2$	-1244
$2 Cr + K(ClO_3) = KCl + Cr_2O_3$	-1237
$8 Sr + Mg(ClO_4)_2 = MgCl_2 + 8 SrO$	-1235
$8 Na + K(ClO_4) = KCl + 4 Na_2O$	-1234
$3 C + 2 Na(ClO_3) = 2 NaCl + 3 CO_2$	-1233
$6 Nb + 5 K(ClO_3) = 5 KCl + 3 Nb_2O_5$	-1233
$16 Pr + 3 Mg(ClO_4)_2 = 3 MgCl_2 + 8 Pr_2O_3$	-1229
$12 Be + 2 Ba(ClO_3)_2 = 2 BaO + 5 BeO + 2 BeCl_2$	-1225
$2 La + Na(ClO_3) = NaCl + La_2O_3$	-1224
$6 Mn + Mg(ClO_4)_2 = MgCl_2 + 2 Mn_3O_4$	-1221
$4 Sr + Li(ClO_4) = LiCl + 4 SrO$	-1216
$26 Ca + 4 Cu(ClO_3)_2 = 2 Cu_2O + 22 CaO + 4 CaCl_2$	-1214
$8 Pr + 3 Li(ClO_4) = 3 LiCl + 4 Pr_2O_3$	-1211
$16 Ce + 3 Mg(ClO_4)_2 = 3 MgCl_2 + 8 Ce_2O_3$	-1208
$8 V + 3 Rb(ClO_4) = 3 RbCl + 4 V_2O_3$	-1202
$16 Nd + 3 Mg(ClO_4)_2 = 3 MgCl_2 + 8 Nd_2O_3$	-1200
$8 La + 3 K(ClO_4) = 3 KCl + 4 La_2O_3$	-1200
$16 Cr + 3 Ba(ClO_4)_2 = 3 BaCl_2 + 8 Cr_2O_3$	-1192
$8 Ce + 3 Li(ClO_4) = 3 LiCl + 4 Ce_2O_3$	-1190
$3 Mn + Li(ClO_4) = LiCl + Mn_3O_4$	-1190
$16 Nb + 5 Ba(ClO_4)_2 = 5 BaCl_2 + 8 Nb_2O_5$	-1189
$6 Na + K(ClO_3) = KCl + 3 Na_2O$	-1185
$35 V + 12 Ag(ClO_4) = 6 Ag_2Cl + 16 V_2O_3 + 3 VCl_2$	-1183
$8 Nd + 3 Li(ClO_4) = 3 LiCl + 4 Nd_2O_3$	-1182
$3 Sr + Na(ClO_3) = NaCl + 3 SrO$	-1179

Table 23 (cont.)

Reaction	Enthalpy, cal/g
$16\ Ga + 3\ Mg(ClO_4)_2 = 3\ MgCl_2 + 8\ Ga_2O_3$	-1177
$2\ Pr + Na(ClO_3) = NaCl + Pr_2O_3$	-1176
$4\ Hf + Mg(ClO_4)_2 = MgCl_2 + 4\ HfO_2$	-1172
$2\ La + K(ClO_3) = KCl + La_2O_3$	-1170
$2\ C + K(ClO_4) = KCl + 2\ CO_2$	-1160
$2\ Ce + Na(ClO_3) = NaCl + Ce_2O_3$	-1157
$4\ Sr + K(ClO_4) = KCl + 4\ SrO$	-1155
$2\ Hf + Li(ClO_4) = LiCl + 2\ HfO_2$	-1153
$8\ Pr + 3\ K(ClO_4) = 3\ KCl + 4\ Pr_2O_3$	-1153
$2\ Nd + Na(ClO_3) = NaCl + Nd_2O_3$	-1150
$8\ Ga + 3\ Li(ClO_4) = 3\ LiCl + 4\ Ga_2O_3$	-1147
$16\ La + 3\ Ba(ClO_4)_2 = 3\ BaCl_2 + 8\ La_2O_3$	-1145
$8\ Ce + 3\ K(ClO_4) = 3\ KCl + 4\ Ce_2O_3$	-1133
$8\ Nd + 3\ K(ClO_4) = 3\ KCl + 4\ Nd_2O_3$	-1127
$16\ Ca + 4\ Na(ClO_4) = 2\ Na_2O + 7\ CaO + 2\ CaCl_2$	-1125
$2\ Pr + K(ClO_3) = KCl + Pr_2O_3$	-1125
$3\ Sr + K(ClO_3) = KCl + 3\ SrO$	-1125
$3\ Hf + 2\ Na(ClO_3) = 2\ NaCl + 3\ HfO_2$	-1121
$16\ B + 3\ Ba(ClO_3)_2 = 3\ BaO + 5\ B_2O_3 + 6\ BCl$	-1116
$12\ Na + Ba(ClO_3)_2 = BaO + 5\ Na_2O + 2\ NaCl$	-1112
$8\ Cr + 3\ Rb(ClO_4) = 3\ RbCl + 4\ Cr_2O_3$	-1108
$8\ Nb + 5\ Rb(ClO_4) = 5\ RbCl + 4\ Nb_2O_5$	-1107

Table 24

CHLORATES AND PERCHLORATES
IN DESCENDING ORDER OF HEAT OF REACTION

Volumetric Heat of Reaction	Gravimetric Heat of Reaction
$Mg(ClO_4)_2$	$Mg(ClO_4)_2$
$LiClO_4$	$LiClO_4$
$AgClO_3$	$NaClO_3$
$NaClO_3$	$KClO_4$
$KClO_4$	$KClO_3$
$Ba(ClO_4)_2$	$Ba(ClO_4)_2$
$RbClO_4$	$RbClO_4$
$KClO_3$	$AgClO_4$
$RbClO_3$	$RbClO_3$
$AgClO_4$	$AgClO_3$
$CsClO_4$	$CsClO_4$
	$Cu(Cl04)_2$
	$Cu(ClO_3)_2$
	$LiClO_3$
	$Ba(ClO_3)_2$

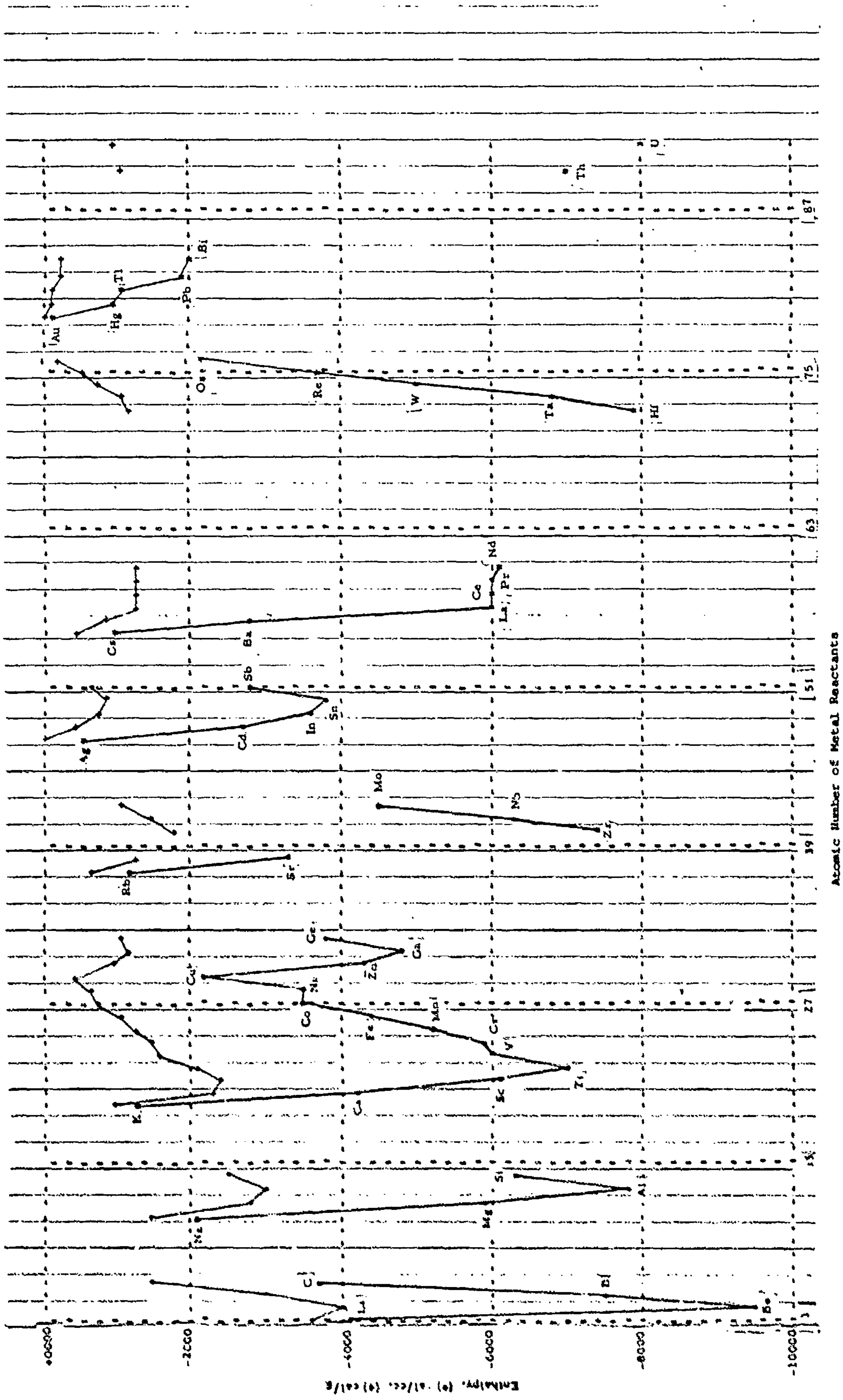


Figure 18

GRAVIMETRIC AND VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH $Mg(ClO_4)_2$

The plot in Figure 19 presents the data in a different manner. The volumetric enthalpies for the reactions of all the chlorates and perchlorates with beryllium are plotted. This allows one to choose an oxidizer for a particular metal reactant, beryllium in this case. Lithium perchlorate is the best oxidizer, and the alkali metal perchlorates follow a decreasing trend in enthalpy in progressing to cesium perchlorate. The gravimetric enthalpies, shown in Figure 20, exhibit similar trends.

The volumetric and gravimetric enthalpies of all 801 chlorate and perchlorate reactions are summarized in Tables 25 and 26, respectively. The same trends noted previously are apparent here.

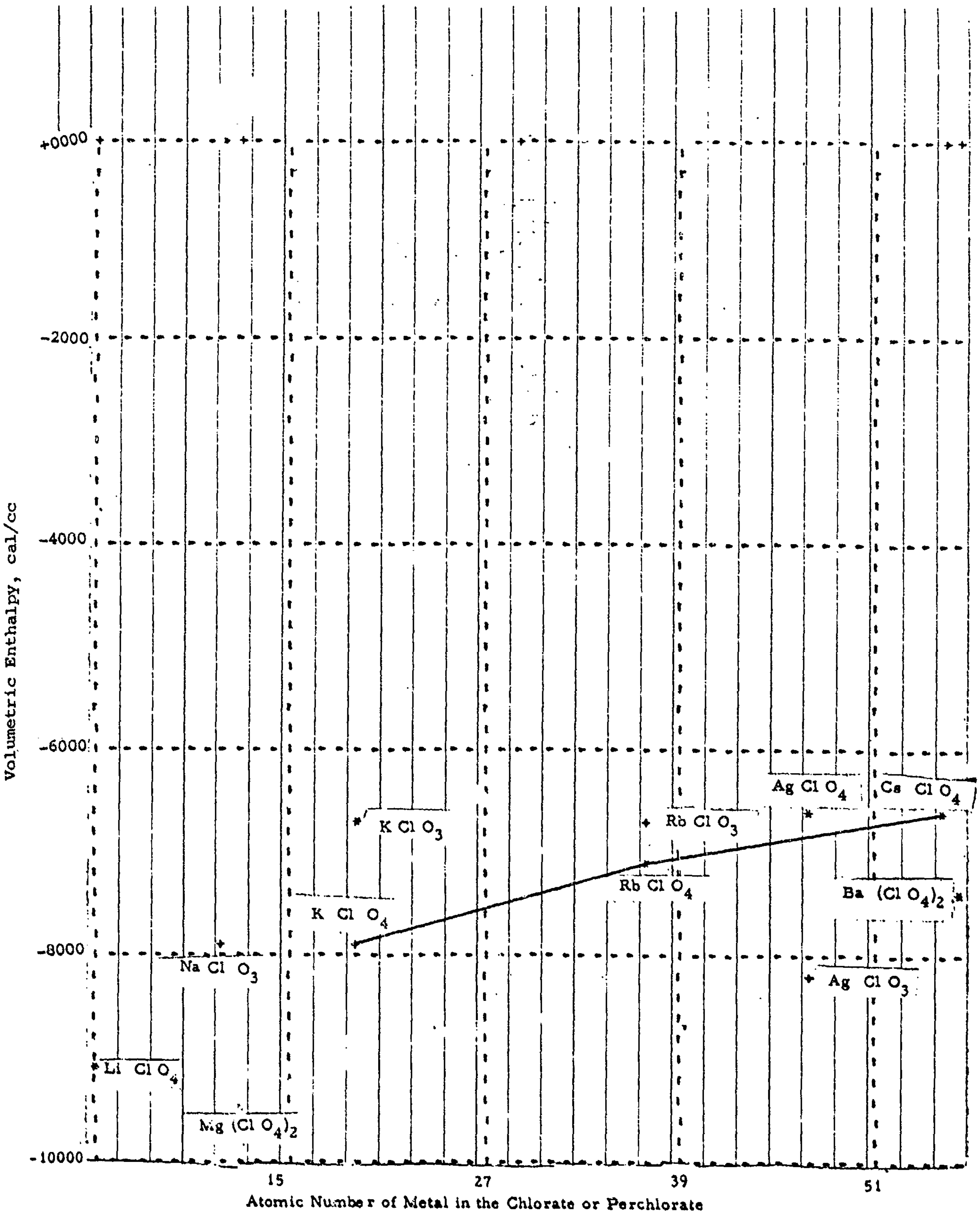


Figure 19

VOLUMETRIC ENTHALPIES OF REACTIONS OF CHLORATES AND PERCHLORATES WITH Be

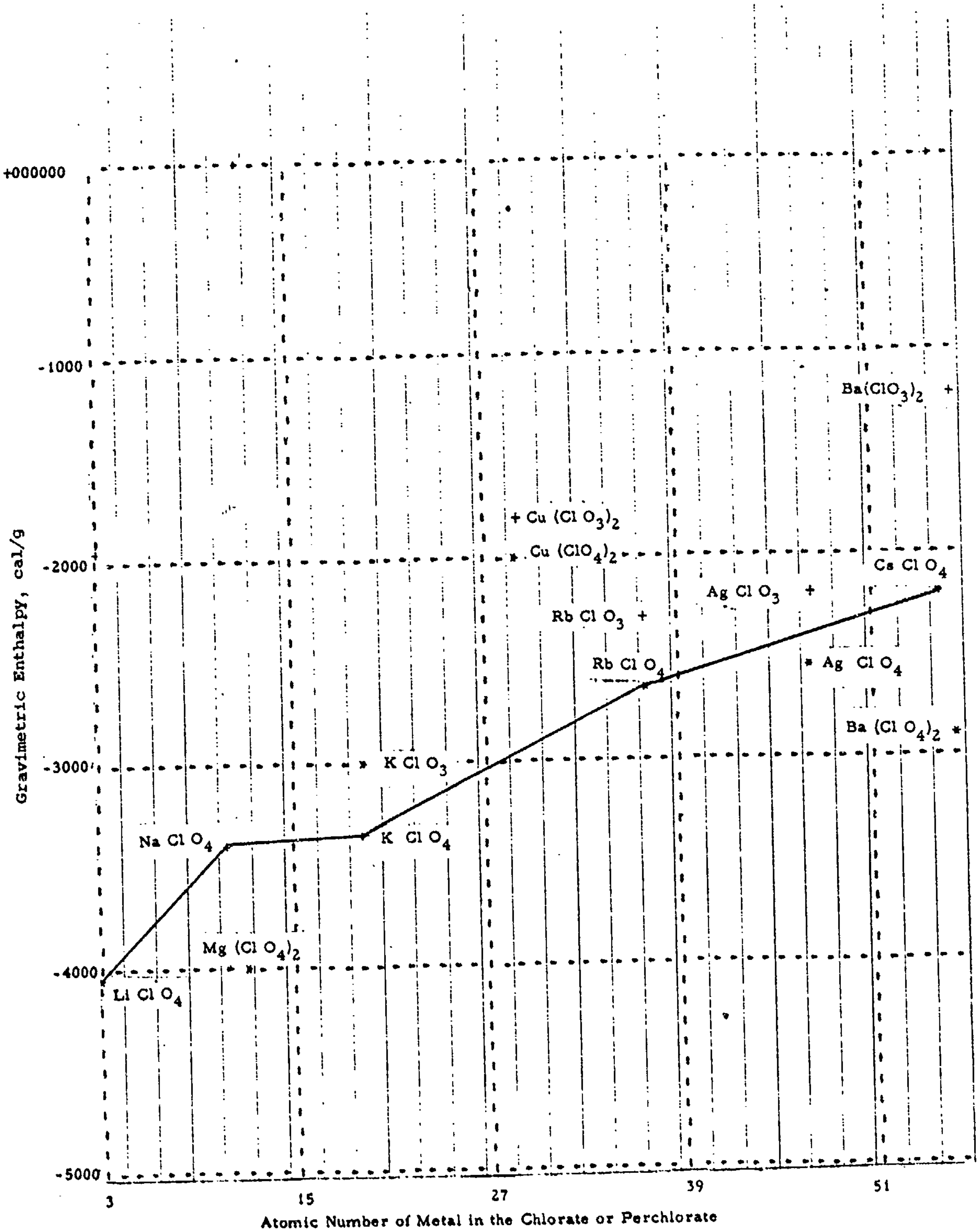


Figure 20

GRAVIMETRIC ENTHALPIES OF REACTIONS
OF CHLORATES AND PERCHLORATES WITH Be

Table 25

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH CHLORATES AND PERCHLORATES
(In descending order from top to bottom and left to right)

	$Mg(ClO_4)_2$	$LiClO_4$	$AgClO_3$	$NaClO_3$	$KClO_4$	$Ba(ClO_4)_2$	$RbClO_4$	$KClO_3$	$RbClO_3$	$AgClO_4$	$CsClO_4$
BE	-9459	-9088	-8103	-7853	-7850	-7302	-7002	-6653	-6616	-6578	-6533
U	-7989	-7670	-6989	-6750	-6720	-6292	-6040	-5779	-5747	-5847	-5662
HF	-7874	-7562	-6905	-6675	-6643	-6228	-5981	-5728	-5696	-5688	-5612
AL	-7742	-7431	-6733	-6562	-6527	-6119	-5875	-5629	-5597	-5553	-5512
B	-7423	-7038	-6242	-6061	-6004	-5562	-5289	-5046	-5010	-4941	-4905
ZR	-7318	-7021	-6448	-6234	-6192	-5817	-5585	-5363	-5332	-5333	-5246
TH	-6998	-6750	-6289	-6102	-6063	-5743	-5542	-5348	-5320	-5320	-5245
TI	-6951	-6658	-6100	-5926	-5876	-5523	-5299	-5095	-5065	-5041	-4977
TA	-6730	-6388	-5767	-5596	-5530	-5155	-4912	-4713	-4679	-4626	-4577
SI	-6289	-5983	-5477	-5316	-5247	-4291	-4701	-4529	-4498	-4454	-4401
NB	-6249	-5914	-5380	-5205	-5128	-4786	-4554	-4381	-4348	-4307	-4243
SC	-6099	-5877	-5568	-5379	-5329	-5071	-4896	-4749	-4724	-4745	-4648
ND	-6036	-5832	-5583	-5374	-5327	-5086	-4922	-4783	-4759	-4802	-4689
LA	-5981	-5786	-5553	-5350	-5305	-5074	-4916	-4782	-4759	-4803	-4691
V	-5980	-5676	-5233	-5054	-4978	-4670	-4455	-4300	-4269	-4263	-4169
PR	-5946	-5747	-5514	-5307	-5259	-5026	-4866	-4732	-4709	-4754	-4639
CE	-5941	-5737	-5514	-5290	-5242	-5005	-4843	-4708	-4685	-4739	-4614
MG	-5886	-5683	-5411	-5243	-5193	-4960	-4799	-4666	-4643	-4661	-4572
CR	-5885	-5565	-5129	-4933	-4851	-4539	-4319	-4167	-4136	-4130	-4031
MN	-5132	-4839	-4626	-4395	-4310	-4074	-3892	-3786	-3758	-3804	-3662
W	-4928	-4587	-4276	-4080	-3965	-3701	-3489	-3392	-3359	-3353	-3239
GA	-4703	-4454	-4230	-4075	-3984	-3773	-3600	-3514	-3488	-3478	-3391
MO	-4449	-4115	-3896	-3697	-3569	-3339	-3138	-3072	-3043	-3048	-2928
FE	-4337	-4038	-3852	-3669	-3551	-3341	-3155	-3090	-3061	-3065	-2946
ZN	-4262	-4029	-3894	-3731	-3637	-3460	-3303	-3240	-3215	-3237	-3121
CA	-4195	-4068	-4031	-3891	-3839	-3725	-3628	-3576	-3560	-3606	-3504
LI	-4068	-3796	-3804	-3642	-3587	-3483	-3389	-3347	-3332	-3396	-3275
SN	-3759	-3521	-3441	-3283	-3175	-3021	-2870	-2832	-2807	-2818	-2706
GE	-3753	-3496	-3416	-3247	-3131	-2971	-2811	-2775	-2749	-2763	-2642
RE	-3654	-3329	-3264	-3058	-2910	-2736	-2553	-2531	-2500	-2526	-2371
C	-3628	-3295	-3236	-3025	-2873	-2699	-2513	-2494	-2463	-2491	-2331
IN	-3570	-3360	-3310	-3166	-3066	-2933	-2797	-2766	-2743	-2756	-2650
NI	-3462	-3206	-3172	-3001	-2878	-2734	-2580	-2559	-2533	-2555	-2423
CO	-3446	-3164	-3135	-2948	-2815	-2676	-2524	-2507	-2481	-2508	-2371
SR	-3211	-3112	-3159	-3029	-2976	-2909	-2837	-2819	-2806	-2862	-2755
SB	-2777	-2561	-2625	-2468	-2347	-2253	-2126	-2135	-2112	-2144	-2010
BA	-2701	-2615	-2701	-2571	-2520	-2473	-2412	-2408	-2397	-2462	-2350
CD	-2630	-2451	-2521	-2385	-2280	-2202	-2093	-2103	-2083	-2123	-1994
CU	-2182	-1935	-2105	-1930	-1784	-1722	-1597	-1644	-1619	-1670	-1505
OS	-2178	-1902	-2104	-1902	-1732	-1665	-1524	-1582	-1555	-1614	-1424
NA	-2078	-1823	-1957	-1698	-1627	-1663	-1565	-1583	-1574	-1690	-1531
BI	-1906	-1742	-1893	-1761	-1649	-1609	-1516	-1556	-1537	-1579	-1448
PB	-1862	-1720	-1855	-1739	-1641	-1606	-1524	-1559	-1543	-1580	-1464
K	-1299	-1080	-1245	-1068	-971	-1040	-931	-966	-957	-1072	-912
RB	-1105	-912	-1065	-910	-787	-878	-727	-799	-764	-920	-710
TL	-1092	-884	-1033	-945	-871	-872	-825	-872	-861	-906	-804
HG	-911	-759	-1023	-889	-764	-771	-697	-778	-761	-821	-669
CS	-911	-752	-882	-759	-655	-735	-606	-678	-651	-773	-584
AU	-107	629	-83	624	837	459	803	724	773	168	770
AG	-523	-190	-460	-329	-217	-248	-193	-284	-270	-332	-189

Table 26

GRAVIMETRIC ENTHALPIES OF REACTIONS OF METALS WITH CHLORATES AND PERCHLORATES
(In descending order from top to bottom and left to right)

	$Mg(ClO_4)_2$	$LiClO_4$	$NaClO_3$	$KClO_4$	$KClO_3$	$Ba(ClO_4)_2$	$RbClO_4$	$AgClO_4$	$RbClO_3$	$AgClO_3$	$CsClO_4$	$Cu(ClO_4)_2$	$Cu(ClO_3)_2$	$LiClO_3$	$NaClO_4$	$Ba(ClO_3)_2$
BE	-3998	-4037	-3374	-3348	-2999	-2891	-2638	-2533	-2281	-2167	-2174	-1978	-1771	-1935	-1729	-1225
LI	-3576	-3463	-2969	-2937	-2665	-2575	-2364	-2351	-2071	-2054	-1077	-3323	-3015	-3310	-3110	-2217
AL	-2933	-2934	-2565	-2530	-2321	-2242	-2067	-1999	-1831	-1747	-1747	-2234	-1997	-1977	-2015	-1398
B	-2912	-2912	-2455	-2408	-2168	-2076	-1878	-1800	-1632	-1533	-1540	-2083	-1692	-1758	-1793	-1116
MG	-2784	-2782	-2474	-2442	-2261	-2191	-2035	-2000	-1821	-1773	-1744	-1478	-1392	-1470	-1301	-1032
SI	-2486	-2473	-2157	-2112	-1935	-1859	-1699	-1644	-1502	-1425	-1422	-707	-649	-650	-479	-403
SC	-2394	-2383	-2156	-2122	-1984	-1924	-1794	-1770	-1622	-1594	-1554	-948	-909	-950	-787	-676
CA	-2257	-2245	-2065	-2034	-1920	-1869	-1757	-1754	-1607	-1594	-1546	-1260	-1214	-1274	-1125	-957
TI	-2071	-2053	-1876	-1839	-1729	-1675	-1561	-1528	-1420	-1349	-1357	-965	-817	-935	-736	-634
ZR	-1777	-1758	-1643	-1610	-1534	-1491	-1403	-1379	-1296	-1257	-1244	-905	-852	-870	-781	-672
V	-1588	-1560	-1451	-1411	-1339	-1292	-1202	-1183	-1104	-1067	-1049	-929	-773	-789	-677	-574
CR	-1462	-1432	-1349	-1299	-1237	-1192	-1108	-1098	-1021	-992	-968	-752	-697	-706	-600	-511
NB	-1448	-1419	-1332	-1292	-1233	-1189	-1107	-1104	-1023	-999	-971	-321	-285	-262	-167	-171
NA	-1445	-1306	-1102	-1238	-1185	-1029	-1075	-981	-1001	-908	-954	-1443	-1391	-1446	-1317	-1112
C	-1433	-1376	-1233	-1140	-1079	-1012	-895	-910	-803	-731	-732	-283	-197	-125	3	-34
LA	-1280	-1262	-1224	-1200	-1170	-1145	-1097	-1102	-1045	-1039	-1012	-531	-533	-539	-453	-444
SR	-1235	-1216	-1179	-1155	-1125	-1100	-1052	-1072	-1001	-1013	-967	-722	-717	-733	-641	-605
PR	-1229	-1211	-1176	-1153	-1125	-1101	-1055	-1060	-1006	-1001	-973	-511	-513	-518	-434	-426
MN	-1221	-1190	-1063	-1028	-997	-965	-906	-917	-854	-850	-813	-432	-609	-612	-514	-468
CE	-1208	-1190	-1157	-1133	-1106	-1082	-1036	-1044	-968	-986	-946	-508	-510	-510	-430	-424
ND	-1200	-1182	-1150	-1127	-1101	-1077	-1032	-1037	-966	-980	-954	-498	-500	-504	-422	-416
GA	-1177	-1147	-1100	-1061	-1025	-989	-924	-932	-866	-854	-821	-936	-705	-686	-703	-538
HF	-1172	-1153	-1121	-1096	-1070	-1046	-1000	-993	-953	-932	-920	-589	-563	-560	-510	-469
FE	-1030	-992	-958	-913	-864	-846	-781	-783	-732	-729	-696	-435	-412	-403	-317	-301
MO	-1030	-989	-952	-904	-771	-833	-765	-707	-652	-713	-611	-451	-393	-370	-300	-260
TH	-1025	-1008	-991	-970	-953	-933	-898	-895	-860	-850	-838	-334	-336	-333	-266	-276
GE	-1024	-986	-981	-906	-877	-839	-774	-792	-745	-723	-678	-17	22	62	82	72
TA	-1012	-988	-965	-935	-914	-887	-840	-850	-800	-794	-765	-467	-430	-417	-375	-328
K	-997	-954	-879	-802	-782	-801	-688	-799	-650	-665	-606	-924	-909	-935	-836	-765
U	-929	-912	-900	-879	-866	-848	-815	-806	-787	-765	-761	-365	-361	-357	-300	-301
ZN	-908	-881	-865	-832	-816	-789	-743	-752	-708	-703	-672	-503	-492	-479	-397	-371
BA	-816	-800	-795	-776	-768	-752	-725	-749	-704	-723	-682	-780	-748	-749	-722	-604
SN	-813	-782	-775	-739	-728	-700	-655	-675	-626	-630	-590	-417	-393	-373	-310	-290
W	-768	-737	-734	-699	-690	-663	-620	-641	-595	-600	-560	-320	-299	-257	-218	-197
CO	-750	-711	-711	-612	-608	-582	-541	-559	-522	-552	-487	-384	-364	-352	-269	-262
IN	-725	-698	-699	-668	-662	-636	-602	-621	-581	-597	-550	-406	-559	-538	-517	-449
NI	-692	-659	-664	-627	-622	-595	-554	-579	-534	-543	-499	-387	-366	-354	-272	-203
SB	-620	-587	-598	-541	-560	-535	-497	-524	-482	-495	-448	-210	-193	-181	-117	-132
RB	-620	-522	-506	-443	-448	-432	-374	-472	-370	-468	-337	-465	-463	-470	-417	-415
RE	-558	-525	-541	-504	-507	-482	-447	-476	-436	-451	-404	-480	-155	-127	-65	-82
CS	-452	-379	-376	-319	-335	-350	-280	-363	-281	-345	-248	-308	-312	-312	-275	-283
CU	-411	-398	-416	-379	-389	-366	-338	-370	-334	-355	-304	-271	-247	-245	-204	-201
CD	-445	-422	-439	-414	-420	-404	-382	-400	-378	-357	-356	-264	-259	-248	-193	-201
BI	-284	-264	-286	-245	-274	-264	-246	-270	-250	-256	-232	-187	-155	-135	-131	-112
CS	-265	-237	-269	-240	-254	-237	-217	-249	-224	-246	-201	-127	-111	-91	-50	-63
PB	-248	-215	-233	-217	-225	-216	-205	-224	-210	-223	-197	-139	-134	-129	-95	-108
TL	-115	-92	-103	-94	-101	-96	-91	-102	-96	-106	-39	-110	-109	-104	-87	-94
HG	-101	-86	-109	-92	-104	-95	-86	-108	-96	-113	-93	-67	-41	-53	-26	-40
AU	-12	64	69	95	89	53	93	21	49	-9	90	18	22	38	72	46
AG	-80	-25	-45	-29	-42	-34	-26	-48	-38	-66	-26	-55	-54	-43	-13	-30

I. Chloride Reactions

The computer was used to examine 10,545 reactions involving 102 chlorides. and 3061 of these reactions were printed. As a class, the chloride reactions are not especially energetic. The highest enthalpy recorded was only -3336 cal/cc, for the reaction of cerium with rhenium pentachloride. The chloride reactions are less energetic than the fluoride, oxide, chlorate, perchlorate, nitrate, nitrite, chromate, and silicide reactions.

The computer output for some of the more energetic reactions is shown in Table 27. Molybdenum and tungsten chlorides behave as some of the better oxidizers in the chloride systems. The reactions of molybdenum pentachloride, tungsten pentachloride, and tungsten hexachloride with various metals are included in the table.

The most energetic reactions are presented in Tables 28 and 29. On a volumetric basis the most effective metal reducing agents are the rare earths (cerium, lanthanum, praseodymium, neodymium, thorium, and uranium), the rare earth predecessors (yttrium and scandium), the alkali metals (lithium), the alkaline earth metals (beryllium, magnesium, and calcium), and hafnium and zirconium. Beryllium is not the most energetic reducing agent in the chloride systems, because the heat of formation of beryllium chloride is comparatively low. The heats of formation of the alkali earth chlorides increase monotonically, while the heats of formation of the alkalis with oxides exhibit a maximum at calcium. The chlorides increase from -122 to -205 kcal/mole from beryllium to barium; and the oxides increase from -146 to -151 kcal/mole from beryllium to calcium and then decrease to -133 kcal/mole at barium. The behavior of beryllium in the chloride systems may be considered normal and its behavior in the oxide systems anomalous. Its effectiveness in the oxide systems compared with the other alkaline earth metals is thus due to the relatively high heat of formation of the oxide. In addition, because of its low atomic volume and weight, it is still an effective reducing agent in the chloride systems, although it is exceeded in efficacy by several other metals including calcium and magnesium. The most effective oxidizers on a volumetric basis are rhenium pentachloride, hexachloroethane, tungsten tetrachloride, tungsten pentachloride, and tungsten hexachloride.

On a gravimetric basis the alkali metals (lithium, sodium, and potassium) are the most effective reducing agents, followed by the alkaline earth metals (calcium, magnesium, and beryllium), the rare earth predecessors (scandium and yttrium), and titanium. The alkali metals are relatively energetic on a gravimetric basis, and are much less energetic on a volumetric basis because of their extremely low densities. The most effective practical oxidizers on a gravimetric basis are the chlorides of carbon

Table 27

DATA ON VARIOUS REACTIONS OF METALS WITH CHLORIDES

	5 Ba	+	2 $MoCl_5$	=	2 Mo	+	5 $BaCl_2$
Heat of formation			-90.80				-205.56
Molecular weight	137.36		273.24		95.95		208.27
Density	3.50		2.93		10.20		
Melting point, °C	704.00		194.00		2610.00		962.00
Boiling point, °C	1638.00		268.00		4800.00		1189.00
Heat of reaction, kcal	-846.20						
Reactants' density	3.22						
Gravimetric enthalpy, cal/g	-686.14						
Volumetric enthalpy, cal/cc	-2210.16						

	5 Be	+	2 $MoCl_5$	=	2 Mo	+	5 $BeCl_2$
Heat of formation			-90.80				-122.30
Molecular weight	9.01		273.24		95.95		79.93
Density	1.85		2.93		10.20		1.90
Melting point, °C	1283.00		194.00		2610.00		405.00
Boiling point, °C	2970.00		268.00		4800.00		547.00
Heat of reaction, kcal	-429.90						
Reactants' density	2.80						
Gravimetric enthalpy, cal/g	-726.74						
Volumetric enthalpy, cal/cc	-2037.45						

	5 Bi	4 $MoCl_5$	4 Mo	5 $BiCl_4$
Heat of formation		-90.80		-120.00
Molecular weight	208.99	273.24	95.95	350.83
Density	9.80	2.93	10.20	
Melting point, °C	271.00	194.00	2610.00	225.00
Boiling point, °C	1420.00	263.00	4800.00	
Heat of reaction, kcal	-236.80			
Reactants' density	4.45			
Gravimetric enthalpy, cal/g	-110.76			
Volumetric enthalpy, cal/cc	-493.43			

Table 27 (cont.)

	5 Mg	+	2 $MoCl_5$	=	2 Mo	+	5 $MgCl_2$
Heat of formation			-90.80				-153.40
Molecular weight	24.32		273.24		95.95		95.23
Density	1.74T		2.93		10.20		2.32
Melting point, °C	650.00P		194.00		2610.00		714.00
Boiling point, °C	1120.00		268.00		4800.00		1418.00
Heat of reaction, kcal	-585.40						
Reactants' density	2.60						
Gravimetric enthalpy, cal/g	-876.24						
Volumetric enthalpy, cal/cc	-2282.04						

	5 Mn	+	2 $MoCl_5$	=	2 Mo	+	5 $MnCl_2$
Heat of formation			-90.80				-115.30
Molecular weight	54.94		273.24		95.95		125.84
Density	7.20		2.93		10.20		2.98
Melting point, °C	1244.00		194.00		2610.00		650.00
Boiling point, °C	2087.00		268.00		4800.00		1190.00
Heat of reaction, kcal	-394.90						
Reactants' density	3.65						
Gravimetric enthalpy, cal/g	-480.39						
Volumetric enthalpy, cal/cc	-1756.73						

	5 Na	+	$MoCl_5$	=	Mo	+	5 NaCl
Heat of formation			-90.80				-98.23
Molecular weight	22.99		273.24		95.95		58.45
Density	.97		2.93		10.20		2.16
Melting point, °C	98.00		194.00		2610.00		808.00
Boiling point, °C	889.00		268.00		4800.00		1465.00
Heat of reaction, kcal	-400.36						
Reactants' density	1.83						
Gravimetric enthalpy, cal/g	-1031.34						
Volumetric enthalpy, cal/cc	-1890.01						

Table 27 (cont.)

	5 Ba	+	2 WCl_5	=	2 W	+	5 $BaCl_2$
Heat of formation			-84.00				-205.56
Molecular weight	137.36		361.21		183.86		208.27
Density	3.50		3.88		19.30		
Melting point, °C	704.00		248.00		380.00		962.00
Boiling point, °C	1638.00		276.00		5900.00		1189.00
Heat of reaction, kcal	-859.80						
Reactants' density	3.68						
Gravimetric enthalpy, cal/g	-610.12						
Volumetric enthalpy, cal/cc	-2246.91						

	5 Be	+	2 WCl_5	=	2 W	+	5 $BeCl_2$
Heat of formation			-84.00				-122.30
Molecular weight	9.01		361.21		183.86		79.93
Density	1.85		3.88		19.30		1.90
Melting point, °C	1283.00		248.00		380.00		405.00
Boiling point, °C	2970.00		276.00		5900.00		547.00
Heat of reaction, kcal	-443.50						
Reactants' density	3.64						
Gravimetric enthalpy, cal/g	-577.86						
Volumetric enthalpy, cal/cc	-2103.99						

	5 Bi	+	4 WCl_5	=	4 W	+	5 $BiCl_4$
Heat of formation			-84.00				-120.00
Molecular weight	208.99		361.21		183.86		350.83
Density	9.80		3.88		19.30		
Melting point, °C	271.00		248.00		380.00		225.00
Boiling point, °C	1420.00		276.00		5900.00		
Heat of reaction, kcal	-254.00						
Reactants' density	5.19						
Gravimetric enthalpy, cal/g	-106.03						
Volumetric enthalpy, cal/cc	-550.59						

Table 27 (cont.)

	5 Mg	+	2 WCl_3	=	2 W	+	5 $MgCl_2$
Heat of formation			-84.00				-153.40
Molecular weight	24.32		361.21		183.86		95.23
Density	1.74		3.88		19.30		2.32
Melting point, °C	650.00		248.00		380.00		714.00
Boiling point, °C	1120.00		276.00		5900.00		1418.00
Heat of reaction,kcal	-599.00						
Reactants' density	3.29						
Gravimetric enthalpy, cal/g	-709.70						
Volumetric enthalpy, cal/cc	-2336.96						

	5 Mn	+	2 WCl_5	=	2 W	+	5 $MnCl_2$
Heat of formation			-84.00				-115.30
Molecular weight	54.94		361.21		183.86		125.84
Density	7.20		3.88		19.30		2.98T
Melting point, °C	1244.00		248.00		380.00		650.00
Boiling point, °C	2087.00		276.00		5900.00		1190.00
Heat of reaction, kcal	-408.50						
Reactants' density	4.44						
Gravimetric enthalpy, cal/g	-409.68						
Volumetric enthalpy, cal/cc	-1818.92						

	5 Na	+	WCl_5	=	W	+	5 NaCl
Heat of formation			-84.00				-98.23
Molecular weight	22.99		361.21		183.86		58.45
Density	.97		3.88		19.30		2.16
Melting point, °C	98.00		248.00		380.00		808.00
Boiling point, °C	889.00		276.00		5900.00		1465.00
Heat of reaction, kcal	-407.16						
Reactants' density	2.25						
Gravimetric enthalpy, cal/g	-855.08						
Volumetric enthalpy, cal/cc	-1923.05						

Table 27 (cont.)

	2 La	+	WCl_6	=	W	+	2 $LaCl_3$
Heat of formation			-98.70				-263.60
Molecular weight	138.92		396.66		183.86		245.29
Density	6.15		3.52		19.30		3.84
Melting point, °C	880.00		284.00		380.00		870.00
Boiling point, °C	1800.00		336.50		5900.00		
Heat of reaction, kcal	-428.50						
Reactants' density	4.27						
Gravimetric enthalpy, cal/g	-635.29						
Volumetric enthalpy, cal/cc	-2714.35						

	6 Li	+	WCl_6	=	W	+	6 LiCl
Heat of formation			-98.70				-97.70
Molecular weight	6.94		396.66		183.86		42.40
Density	.53		3.52		19.30		2.07T
Melting point, °C	180.00		284.00F		380.00		610.00
Boiling point, °C	1326.00		336.50		5900.00		1382.00
Heat of reaction, kcal	-487.50						
Reactants' density	2.30						
Gravimetric enthalpy, cal/g	-1112.25						
Volumetric enthalpy, cal/cc	-2556.84						

	3 Mg	+	WCl_6	=	W	+	3 $MgCl_2$
Heat of formation			-98.70				-153.40
Molecular weight	24.32		396.66		163.86		95.23
Density	1.74		3.52		19.30		2.32
Melting point, °C	650.00		284.00		380.00		714.00
Boiling point, °C	1120.00		336.50		5900.00		1418.00
Heat of reaction, kcal	-361.50						
Reactants' density	3.04						
Gravimetric enthalpy, cal/g	-769.77						
Volumetric enthalpy, cal/cc	-2338.01						

Table 28

MOST ENERGETIC CHLORIDE REACTIONS WITH METALS, IN TERMS OF VOLUMETRIC ENTHALPY

Reaction							Enthalpy, cal/cc
5 Ce	+	3 $ReCl_5$	=	3 Re	+	5 $CeCl_3$	-3336
5 La	+	3 $ReCl_5$	=	3 Re	+	5 $LaCl_3$	-3301
5 Pr	+	3 $ReCl_5$	=	3 Re	+	5 $PrCl_3$	-3259
5 Nd	+	3 $ReCl_5$	=	3 Re	+	5 $NdCl_3$	-3244
5 Y	+	3 $ReCl_5$	=	3 Re	+	5 YCl_3	-3178
2 Ce	+	C_2Cl_6	=	2 C	+	2 $CeCl_3$	-3047
2 La	+	C_2Cl_6	=	2 C	+	2 $LaCl_3$	-3025
5 Li	+	$ReCl_5$	=	Re	+	5 LiCl	-3006
5 U	+	3 $ReCl_5$	=	3 Re	+	5 UCl_3	-2986
2 Pr	+	C_2Cl_6	=	2 C	+	2 $PrCl_3$	-2986
2 Nd	+	C_2Cl_6	=	2 C	+	2 $NdCl_3$	-2970
5 Ca	+	2 $ReCl_5$	=	2 Re	+	5 $CaCl_2$	-2916
5 Hf	+	3 $ReCl_5$	=	3 Re	+	5 $HfCl_3$	-2899
2 Y	+	C_2Cl_6	=	2 C	+	2 YCl_3	-2897
5 Mg	+	2 $ReCl_5$	=	2 Re	+	5 $MgCl_2$	-2872
5 Sc	+	3 $ReCl_5$	=	3 Re	+	5 $ScCl_3$	-2860
5 Th	+	4 $ReCl_5$	=	4 Re	+	5 $ThCl_4$	-2859
5 Zr	+	3 $ReCl_5$	=	3 Re	+	5 $ZrCl_3$	-2824
6 Li	+	C_2Cl_6	=	2 C	+	6 LiCl	-2814
4 Ce	+	3 WCl_4	=	3 W	+	4 $CeCl_3$	-2807
4 La	+	3 WCl_4	=	3 W	+	4 $LaCl_3$	-2788
4 Pr	+	3 WCl_4	=	3 W	+	4 $PrCl_3$	-2745
3 Ca	+	C_2Cl_6	=	2 C	+	3 $CaCl_2$	-2735
5 Ce	+	3 WCl_5	=	3 W	+	5 $CeCl_3$	-2731
2 Ce	+	WCl_6	=	W	+	2 $CeCl_3$	-2730
5 Be	+	2 $ReCl_5$	=	2 Re	+	5 $BeCl_2$	-2729
4 Nd	+	3 WCl_4	=	3 W	+	4 $NdCl_3$	-2726
2 U	+	C_2Cl_6	=	2 C	+	2 UCl_3	-2725
5 La	+	3 WCl_5	=	3 W	+	5 $LaCl_3$	-2715

Table 28 (cont.)

Reaction	Enthalpy, cal/cc
$2\ La + WCl_6 = W + 2\ LaCl_3$	-2714
$5\ Sr + 2\ ReCl_5 = 2\ Re + 5\ SrCl_2$	-2682
$5\ Ce + 3\ MoCl_5 = 3\ Mo + 5\ CeCl_3$	-2676
$5\ Pr + 3\ WCl_5 = 3\ W + 5\ PrCl_3$	-2672
$2\ Pr + WCl_6 = W + 2\ PrCl_3$	-2671
$5\ La + 3\ MoCl_5 = 3\ Mo + 5\ LaCl_3$	-2661
$3\ Mg + C_2Cl_6 = 2\ C + 3\ MgCl_2$	-2656
$4\ Ce + 3\ C_2Cl_4 = 6\ C + 4\ CeCl_3$	-2655
$2\ Hf + C_2Cl_6 = 2\ C + 2\ HfCl_3$	-2655
$5\ Nd + 3\ WCl_5 = 3\ W + 5\ NdCl_3$	-2653
$2\ Nd + WCl_6 = W + 2\ NdCl_3$	-2652
$4\ La + 3\ C_2Cl_4 = 6\ C + 4\ LaCl_3$	-2643
$2\ Sc + C_2Cl_6 = 2\ C + 2\ ScCl_3$	-2638
$4\ Y + 3\ WCl_4 = 3\ W + 4\ YCl_3$	-2632
$3\ Th + 2\ C_2Cl_6 = 4\ C + 3\ ThCl_4$	-2629
$5\ Pr + 3\ MoCl_5 = 3\ Mo + 5\ PrCl_3$	-2617
$4\ Li + WCl_4 = W + 4\ LiCl$	-2612
$4\ Pr + 3\ C_2Cl_4 = 6\ C + 4\ PrCl_3$	-2609
$5\ Nd + 3\ MoCl_5 = 3\ Mo + 5\ NdCl_3$	-2598
$2\ Zr + C_2Cl_6 = 2\ C + 2\ ZrCl_3$	-2596
$4\ Nd + 3\ C_2Cl_4 = 6\ C + 4\ NdCl_3$	-2593
$5\ Ba + 2\ ReCl_5 = 2\ Re + 5\ BaCl_2$	-2576
$5\ Y + 3\ WCl_5 = 3\ W + 5\ YCl_3$	-2558
$2\ Y + WCl_6 = W + 2\ YCl_3$	-2558
$5\ Li + WCl_5 = W + 5\ LiCl$	-2556
$6\ Li + WCl_6 = W + 6\ LiCl$	-2556
$3\ Sr + C_2Cl_6 = 2\ C + 3\ SrCl_2$	-2547
$2\ Ca + WCl_4 = W + 2\ CaCl_2$	-2529
$4\ Li + C_2Cl_4 = 2\ C + 4\ LiCl$	-2523
$4\ Ce + 3\ CCl_4 = 3\ C + 4\ CeCl_3$	-2523
$Ce + MoCl_3 = Mo + 1\ CeCl_3$	-2521

Table 28 (cont.)

Reaction	Enthalpy, cal/cc
4 Y + 3 C_2Cl_4 = 6 C + 4 YCl_3	-2516
4 La + 3 CCl_4 = 3 C + 4 $LaCl_3$	-2513
5 Li + $MoCl_5$ = Mo + 5 LiCl	-2512
La + $MoCl_3$ = Mo + $LaCl_3$	-2509
5 Y + 3 $MoCl_5$ = 3 Mo + 5 YCl_3	-2500
3 Be + C_2Cl_6 = 2 C + 3 $BeCl_2$	-2494
3 Ca + WCl_6 = W + 3 $CaCl_2$	-2477
5 Ca + 2 WCl_5 = 2 W + 5 $CaCl_2$	-2476
4 Pr + 3 CCl_4 = 3 C + 4 $PrCl_3$	-2476
Pr + $MoCl_3$ = Mo + $PrCl_3$	-2464
3 Ba + C_2Cl_6 = 2 C + 3 $BaCl_2$	-2462
4 Nd + 3 CCl_4 = 3 C + 4 $NdCl_3$	-2459
2 Ca + C_2Cl_4 = 2 C + 2 $CaCl_2$	-2457
Nd + $MoCl_3$ = Mo + $NdCl_3$	-2444
4 U + 3 WCl_4 = 3 W + 4 UCl_3	-2436
5 Ca + 2 $MoCl_5$ = 2 Mo + 5 $CaCl_2$	-2432
4 Li + CCl_4 = C + 4 LiCl	-2408
2 Mg + WCl_4 = W + 2 $MgCl_2$	-2396
5 Ce + 3 $NbCl_5$ = 3 Nb + 5 $CeCl_3$	-2395
3 Li + $MoCl_3$ = Mo + 3 LiCl	-2387
5 La + 3 $NbCl_5$ = 3 Nb + 5 $LaCl_3$	-2386
5 Ce + 3 $TaCl_5$ = 3 Ta + 5 $CeCl_3$	-2374
4 Y + 3 CCl_4 = 3 C + 4 YCl_3	-2371
2 U + WCl_6 = W + 2 UCl_3	-2369
5 U + 3 WCl_5 = 3 W + 5 UCl_3	-2368
4 U + 3 C_2Cl_4 = 6 C + 4 UCl_3	-2368
4 Hf + 3 WCl_4 = 3 W + 4 $HfCl_3$	-2365
4 Sc + 3 WCl_4 = 3 W + 4 $ScCl_3$	-2365
5 La + 3 $TaCl_5$ = 3 Ta + 5 $LaCl_3$	-2365
2 Sr + WCl_4 = W + 2 $SrCl_2$	-2357
Ce + $AuCl_3$ = Au + $CeCl_3$	-2349

Table 28 (cont.)

Reaction										Enthalpy, cal/cc
	Th	+		WCl_4	=		W	+		$ThCl_4$	-2347
2	Mg	+		C_2Cl_4	=	2	C	+	2	$MgCl_2$	-2343
	La	+		$AuCl_3$	=		Au	+		$LaCl_3$	-2342
5	Pr	+	3	$NbCl_5$	=	3	Nb	+	5	$PrCl_3$	-2341
5	Mn	+	2	$ReCl_5$	=	2	Re	+	5	$MnCl_2$	-2339
2	Ca	+		CCl_4	=		C	+	2	$CaCl_2$	-2339
3	Mg	+		WCl_6	=		W	+	3	$MgCl_2$	-2338
	Y	+		$MoCl_3$	=		Mo	+		YCl_3	-2336
5	Mg	+	2	WCl_5	=	2	W	+	5	$MgCl_2$	-2336
2	Sr	+		C_2Cl_4	=	2	C	+	2	$SrCl_2$	-2324
5	Nd	+	3	$NbCl_5$	=	3	Nb	+	5	$NdCl_3$	-2320
5	Pr	+	3	$TaCl_5$	=	3	Ta	+	5	$PrCl_3$	-2320
4	Sc	+	3	C_2Cl_4	=	6	C	+	4	$ScCl_3$	-2318
3	Sr	+		WCl_6	=		W	+	3	$SrCl_2$	-2316
4	Hf	+	3	C_2Cl_4	=	6	C	+	4	$HfCl_3$	-2316
5	Sr	+	2	WCl_5	=	2	W	+	5	$SrCl_2$	-2315
3	Ca	+	2	$MoCl_3$	=	2	Mo	+	3	$CaCl_2$	-2307
5	U	+	3	$MoCl_5$	=	3	Mo	+	5	UCl_3	-2306
4	Zr	+	3	WCl_4	=	3	W	+	4	$ZrCl_3$	-2306
2	Sc	+		WCl_6	=		W	+	2	$ScCl_3$	-2306
	Pr	+		$AuCl_3$	=		Au	+		$PrCl_3$	-2306
5	Sc	+	3	WCl_5	=	3	W	+	5	$ScCl_3$	-2305
	Th	+		C_2Cl_4	=	2	C	+		$ThCl_4$	-2304
2	Hf	+		WCl_6	=		W	+	2	$HfCl_3$	-2302
5	Hf	+	3	WCl_5	=	3	W	+	5	$HfCl_3$	-2301
5	Nd	+	3	$TaCl_5$	=	3	Ta	+	5	$NdCl_3$	-2298
5	Li	+		$NbCl_5$	=		Nb	+	5	LiCl	-2288
	Nd	+		$AuCl_3$	=		Au	+		$NdCl_3$	-2288
3	Th	+	2	WCl_6	=	2	W	+	3	$ThCl_4$	-2287
5	Th	+	4	WCl_5	=	4	W	+	5	$ThCl_4$	-2285
2	Ba	+		WCl_4	=		W	+	2	$BaCl_2$	-2283

Table 28 (cont.)

Reaction	Enthalpy, cal/cc
5 Mg + 2 $MoCl_5$ = 2 Mo + 5 $MgCl_2$	-2282
5 Al + 3 $ReCl_5$ = 3 Re + 5 $AlCl_3$	-2278
5 Sr + 2 $MoCl_5$ = 2 Mo + 5 $SrCl_2$	-2276
4 Zr + 3 C_2Cl_4 = 6 C + 4 $ZrCl_3$	-2273
5 Li + $TaCl_5$ = Ta + 5 LiCl	-2270
3 Li + $AuCl_3$ = Au + 3 LiCl	-2266
2 Ba + C_2Cl_4 = 2 C + 2 $BaCl_2$	-2265
5 Sc + 3 $MoCl_5$ = 3 Mo + 5 $ScCl_3$	-2248
3 Ba + WCl_6 = W + 3 $BaCl_2$	-2247
2 Zr + WCl_6 = W + 2 $ZrCl_3$	-2247
5 Ba + 2 WCl_5 = 2 W + 5 $BaCl_2$	-2246
5 Zr + 3 WCl_5 = 3 W + 5 $ZrCl_3$	-2245
5 Hf + 3 $MoCl_5$ = 3 Mo + 5 $HfCl_3$	-2240
5 Ti + 3 $ReCl_5$ = 3 Re + 5 $TiCl_3$	-2229
2 Ce + 3 WCl_2 = 3 W + 2 $CeCl_3$	-2228
5 Th + 4 $MoCl_5$ = 4 Mo + 5 $ThCl_4$	-2226
2 La + 3 WCl_2 = 3 W + 2 $LaCl_3$	-2223
2 Sr + CCl_4 = C + 2 $SrCl_2$	-2213
5 Ba + 2 $MoCl_5$ = 2 Mo + 5 $BaCl_2$	-2210
4 U + 3 CCl_4 = 3 C + 4 UCl_3	-2210
5 Ca + 2 $NbCl_5$ = 2 Nb + 5 $CaCl_2$	-2209
5 Y + 3 $NbCl_5$ = 3 Nb + 5 YCl_3	-2208
3 Ca + 2 $AuCl_3$ = 2 Au + 3 $CaCl_2$	-2201
2 Ce + 3 $MoCl_2$ = 3 Mo + 2 $CeCl_3$	-2200
2 Mg + CCl_4 = C + 2 $MgCl_2$	-2198
Y + $AuCl_3$ = Au + YCl_3	-2197
2 La + 3 $MoCl_2$ = 3 Mo + 2 $LaCl_3$	-2196
5 Ca + 2 $TaCl_5$ = 2 Ta + 5 $CaCl_2$	-2191
3 Mn + C_2Cl_6 = 2 C + 3 $MnCl_2$	-2188
5 Na + $ReCl_5$ = Re + 5 NaCl	-2185
5 Zr + 3 $MoCl_5$ = 3 Mo + 5 $ZrCl_3$	-2185

Table 28 (cont.)

Reaction	Enthalpy, cal/cc
$5\ Y + 3\ TaCl_5 = 3\ Ta + 5\ YCl_3$	-2184
$2\ Pr + 3\ WCl_2 = 3\ W + 2\ PrCl_3$	-2182
$2\ Be + C_2Cl_4 = 2\ C + 2\ BeCl_2$	-2168
$4\ Sc + 3\ CCl_4 = 3\ C + 4\ ScCl_3$	-2168
$3\ Sr + 2\ MoCl_3 = 2\ Mo + 3\ SrCl_2$	-2166
$2\ Be + WCl_4 = W + 2\ BeCl_2$	-2164
$2\ Nd + 3\ WCl_2 = 3\ W + 2\ NdCl_3$	-2162
$2\ Li + WCl_2 = W + 2\ LiCl$	-2159
$2\ Ba + CCl_4 = C + 2\ BaCl_2$	-2159
$4\ Hf + 3\ CCl_4 = 3\ C + 4\ HfCl_3$	-2157
$2\ Pr + 3\ MoCl_2 = 3\ Mo + 2\ PrCl_3$	-2153
$Th + CCl_4 = C + ThCl_4$	-2148
$2\ Ce + 3\ CuCl_2 = 3\ Cu + 2\ CeCl_3$	-2144
$2\ La + 3\ CuCl_2 = 3\ Cu + 2\ LaCl_3$	-2141
$U + MoCl_3 = Mo + UCl_3$	-2136
$2\ Al + C_2Cl_6 = 2\ C + 2\ AlCl_3$	-2135
$2\ Li + MoCl_2 = Mo + 2\ LiCl$	-2134
$2\ Nd + 3\ MoCl_2 = 3\ Mo + 2\ NdCl_3$	-2132
$3\ Mg + 2\ MoCl_3 = 2\ Mo + 3\ MgCl_2$	-2130
$6\ Na + C_2Cl_6 = 2\ C + 6\ NaCl$	-2119
$4\ Zr + 3\ CCl_4 = 3\ C + 4\ ZrCl_3$	-2113
$3\ Ba + 2\ MoCl_3 = 2\ Mo + 3\ BaCl_2$	-2108
$3\ Be + WCl_6 = W + 3\ BeCl_2$	-2106
$5\ Be + 2\ WCl_5 = 2\ W + 5\ BeCl_2$	-2103
$2\ Pr + 3\ CuCl_2 = 3\ Cu + 2\ PrCl_3$	-2097
$2\ Ti + C_2Cl_6 = 2\ C + 2\ TiCl_3$	-2096
$5\ V + 2\ ReCl_5 = 2\ Re + 5\ VCl_2$	-2092
$3\ Sr + 2\ AuCl_3 = 2\ Au + 3\ SrCl_2$	-2092
$Sc + MoCl_3 = Mo + ScCl_3$	-2090
$Ca + WCl_2 = W + CaCl_2$	-2089
$2\ Li + CuCl_2 = Cu + 2\ LiCl$	-2088

Table 28 (cont.)

Reaction	Enthalpy, cal/cc
$5\,Sr + 2\,NbCl_5 = 2\,Nb + 5\,SrCl_2$	-2082
$2\,Nd + 3\,CuCl_2 = 3\,Cu + 2\,NdCl_3$	-2076
$Ce + FeCl_3 = Fe + CeCl_3$	-2075
$La + FeCl_3 = Fe + LaCl_3$	-2073
$Hf + MoCl_3 = Mo + HfCl_3$	-2072
$5\,Sr + 2\,TaCl_5 = 2\,Ta + 5\,SrCl_2$	-2065
$3\,Th + 4\,MoCl_3 = 4\,Mo + 3\,ThCl_4$	-2063
$Ca + MoCl_2 = Mo + CaCl_2$	-2062
$2\,Y + 3\,WCl_2 = 3\,W + 2\,YCl_3$	-2056
$3\,Ba + 2\,AuCl_3 = 2\,Au + 3\,BaCl_2$	-2048
$3\,Mg + 2\,AuCl_3 = 2\,Au + 3\,MgCl_2$	-2042
$Ce + 3\,AuCl = 3\,Au + CeCl_3$	-2040
$La + 3\,AuCl = 3\,Au + LaCl_3$	-2039
$U + AuCl_3 = Au + UCl_3$	-2039
$5\,Be + 2\,MoCl_5 = 2\,Mo + 5\,BeCl_2$	-2037
$5\,Ba + 2\,NbCl_5 = 2\,Nb + 5\,BaCl_2$	-2031

Table 29

MOST ENERGETIC CHLORIDE REACTIONS WITH METALS, IN TERMS OF GRAVIMETRIC ENTHALPY

Reaction	Enthalpy, cal/g
$Li + BCl = B + LiCl$	-2316
$4\ Li + C_2Cl_4 = 2\ C + 4\ LiCl$	-2002
$4\ Li + CCl_4 = C + 4\ LiCl$	-1968
$6\ Li + C_2Cl_6 = 2\ C + 6\ LiCl$	-1933
$Ca + 2\ BCl = 2\ B + CaCl_2$	-1818
$Na + BCl = B + NaCl$	-1787
$Mg + 2\ BCl = 2\ B + MgCl_2$	-1750
$Be + 2\ BCl = 2\ B + BeCl_2$	-1708
$Sc + 3\ BCl = 3\ B + ScCl_3$	-1619
$2\ Ca + C_2Cl_4 = 2\ C + 2\ CaCl_2$	-1532
$K + BCl = B + KCl$	-1519
$4\ Na + C_2Cl_4 = 2\ C + 4\ NaCl$	-1512
$2\ Ca + CCl_4 = C + 2\ CaCl_2$	-1481
$Al + 3\ BCl = 3\ B + AlCl_3$	-1465
$4\ Na + CCl_4 = C + 4\ NaCl$	-1463
$3\ Ca + C_2Cl_6 = 2\ C + 3\ CaCl_2$	-1462
$6\ Na + C_2Cl_6 = 2\ C + 6\ NaCl$	-1444
$6\ Li + MoCl_6 = Mo + 6\ LiCl$	-1416
$2\ Mg + C_2Cl_4 = 2\ C + 2\ MgCl_2$	-1416
$3\ Li + BCl_3 = B + 3\ LiCl$	-1399
$Sr + 2\ BCl = 2\ B + SrCl_2$	-1382
$Y + 3\ BCl = 3\ B + YCl_3$	-1368
$2\ Mg + CCl_4 = C + 2\ MgCl_2$	-1350
$Li + AlCl = Al + LiCl$	-1337
$3\ Mg + C_2Cl_6 = 2\ C + 3\ MgCl_2$	-1330
$2\ Be + C_2Cl_4 = 2\ C + 2\ BeCl_2$	-1313
$4\ Li + CrCl_4 = Cr + 4\ LiCl$	-1294
$Ti + 3\ BCl = 3\ B + TiCl_3$	-1294
$5\ Li + MoCl_5 = Mo + 5\ LiCl$	-1291

Table 29 (cont.)

Reaction	Enthalpy, cal/g
$4\ Sc + 3\ C_2Cl_4 = 6\ C + 4\ ScCl_3$	-1290
$4\ K + C_2Cl_4 = 2\ C + 4\ KCl$	-1283
$4\ Li + MnCl_4 = Mn + 4\ LiCl$	-1250
$Zr + 3\ BCl = 3\ B + ZrCl_3$	-1237
$4\ K + CCl_4 = C + 4\ KCl$	-1235
$2\ Be + CCl_4 = C + 2\ BeCl_2$	-1229
$La + 3\ BCl = 3\ B + LaCl_3$	-1225
$5\ Li + NbCl_5 = Nb + 5\ LiCl$	-1224
$6\ K + C_2Cl_6 = 2\ C + 6\ KCl$	-1224
$4\ Sc + 3\ CCl_4 = 3\ C + 4\ ScCl_3$	-1221
$3\ Be + C_2Cl_6 = 2\ C + 3\ BeCl_2$	-1208
$Ce + 3\ BCl = 3\ B + CeCl_3$	-1208
$2\ Sc + C_2Cl_6 = 2\ C + 2\ ScCl_3$	-1204
$4\ Li + SiCl_4 = Si + 4\ LiCl$	-1203
$Si + 4\ BCl = 4\ B + SiCl_4$	-1197
$Pr + 3\ BCl = 3\ B + PrCl_3$	-1196
$4\ Li + MoCl_4 = Mo + 4\ LiCl$	-1174
$Nd + 3\ BCl = 3\ B + NdCl_3$	-1169
$2\ Sr + C_2Cl_4 = 2\ C + 2\ SrCl_2$	-1152
$5\ Li + Sb\ Cl_5 = Sb + 5\ LiCl$	-1149
$4\ Li + VCl_4 = V + 4\ LiCl$	-1146
$Li + GeCl = Ge + LiCl$	-1131
$Mn + 2\ BCl = 2\ B + MnCl_2$	-1128
$V + 3\ BCl = 3\ B + VCl_3$	-1126
$3\ Ca + MoCl_6 = Mo + 3\ CaCl_2$	-1119
$6\ Na + MoCl_6 = Mo + 6\ NaCl$	-1118
$Ba + 2\ BCl = 2\ B + BaCl_2$	-1116
$6\ Li + WCl_6 = W + 6\ LiCl$	-1112
$Cr + 3\ BCl = 3\ B + CrCl_3$	-1107
$2\ Sr + CCl_4 = C + 2\ SrCl_2$	-1102
$3\ Sr + C_2Cl_6 = 2\ C + 3\ SrCl_2$	-1092

Table 29 (cont.)

Reaction	Enthalpy, cal/g
$Ca + 2\,AlCl = 2\,Al + CaCl_2$	-1092
$Na + AlCl = Al + NaCl$	-1092
$4\,Y + 3\,C_2Cl_4 = 6\,C + 4\,YCl_3$	-1090
$4\,Al + 3\,C_2Cl_4 = 6\,C + 4\,AlCl_3$	-1083
$4\,Li + GeCl_4 = Ge + 4\,LiCl$	-1076
$3\,Li + FeCl_3 = Fe + 3\,LiCl$	-1072
$5\,Li + ReCl_5 = Re + 5\,LiCl$	-1050
$3\,Na + BCl_3 = B + 3\,NaCl$	-1045
$3\,Ca + 2\,BCl_3 = 2\,B + 3\,CaCl_2$	-1043
$5\,Na + MoCl_5 = Mo + 5\,NaCl$	-1031
$5\,Ca + 2\,MoCl_5 = 2\,Mo + 5\,CaCl_2$	-1028
$4\,Y + 3\,CCl_4 = 3\,C + 4\,YCl_3$	-1027
$3\,Li + MoCl_3 = Mo + 3\,LiCl$	-1022
$5\,Li + WCl_5 = W + 5\,LiCl$	-1021
$2\,Y + C_2Cl_6 = 2\,C + 2\,YCl_3$	-1016
$4\,Na + CrCl_4 = Cr + 4\,NaCl$	-1010
$2\,Ca + CrCl_4 = Cr + 2\,CaCl_2$	-1007
$3\,Li + MnCl_3 = Mn + 3\,LiCl$	-1005
$Na + GeCl = Ge + NaCl$	- 997
$Ca + 2\,GeCl = 2\,Ge + CaCl_2$	- 994
$4\,La + 3\,C_2Cl_4 = 6\,C + 4\,LaCl_3$	- 992
$4\,Al + 3\,CCl_4 = 3\,C + 4\,AlCl_3$	- 992
$2\,Li + CuCl_2 = Cu + 2\,LiCl$	- 985
$6\,K + MoCl_6 = Mo + 6\,KCl$	- 984
$Hf + 4\,BCl = 4\,B + HfCl_4$	- 982
$4\,Na + MnCl_4 = Mn + 4\,NaCl$	- 979
$2\,Al + C_2Cl_6 = 2\,C + 2\,AlCl_3$	- 978
$K + AlCl = Al + KCl$	- 977
$5\,Na + NbCl_5 = Nb + 5\,NaCl$	- 976
$4\,Ce + 3\,C_2Cl_4 = 6\,C + 4\,CeCl_3$	- 975
$Rb + BCl + B + RbCl$	- 975

Table 29 (cont.)

Reaction	Enthalpy, cal/g
$2\,Ca + MnCl_4 = Mn + 2\,CaCl_2$	- 974
$4\,Li + TiCl_4 = Ti + 4\,LiCl$	- 972
$5\,Ca + 2\,NbCl_5 = 2\,Nb + 5\,CaCl_2$	- 971
$3\,Mg + MoCl_6 = Mo + 3\,MgCl_2$	- 969
$Ga + 3\,BCl = 3\,B + GaCl_3$	- 969
$4\,Pr + 3\,C_2Cl_4 = 6\,C + 4\,PrCl_3$	- 963
$Mg + 2\,AlCl = 2\,Al + MgCl_2$	- 962
$4\,Zr + 3\,C_2Cl_4 = 6\,C + 4\,ZrCl_3$	- 954
$Zn + 2\,BCl = 2\,B + ZnCl_2$	- 953
$4\,Na + MoCl_4 = Mo + 4\,NaCl$	- 952
$Li + GaCl = Ga + LiCl$	- 951
$2\,Ca + MoCl_4 = Mo + 2\,CaCl_2$	- 946
$4\,Ti + 3\,C_2Cl_4 = 6\,C + 4\,TiCl_3$	- 944
$4\,La + 3\,CCl_4 = 3\,C + 4\,LaCl_3$	- 938
$4\,Nd + 3\,C_2Cl_4 = 6\,C + 4\,NdCl_3$	- 938
$5\,Li + TaCl_5 = Ta + 5\,LiCl$	- 937
$5\,Na + SbCl_5 = Sb + 5\,NaCl$	- 933
$2\,La + C_2Cl_6 = 2\,C + 2\,LaCl_3$	- 931
$4\,Li + ReCl_4 = Re + 4\,LiCl$	- 929
$Th + 4\,BCl = 4\,B + ThCl_4$	- 928
$K + GeCl = Ge + KCl$	- 928
$5\,Ca + 2\,SbCl_5 = 2\,Sb + 5\,CaCl_2$	- 927
$2\,Ba + C_2Cl_4 = 2\,C + 2\,BaCl_2$	- 926
$4\,Ce + 3\,CCl_4 = 3\,C + 4\,CeCl_3$	- 921
$6\,Na + WCl_6 = W + 6\,NaCl$	- 917
$5\,K + MoCl_5 = Mo + 5\,KCl$	- 917
$6\,Li + Al_2Cl_6 = 2\,Al + 6\,LiCl$	- 916
$4\,Na + SiCl_4 = Si + 4\,NaCl$	- 916
$2\,Ce + C_2Cl_6 = 2\,C + 2\,CeCl_3$	- 914
$3\,Ca + WCl_6 = W + 3\,CaCl_2$	- 911

Table 29 (cont.)

Reaction	Enthalpy, cal/g
$4\,Pr + 3\,CCl_4 = 3\,C + 4\,PrCl_3$	- 908
$4\,Li + OsCl_4 = Os + 4\,LiCl$	- 908
$Mg + 2\,GeCl = 2\,Ge + MgCl_2$	- 907
$2\,Ca + SiCl_4 = Si + 2\,CaCl_2$	- 907
$3\,K + BCl_3 = B + 3\,KCl$	- 906
$4\,Li + WCl_4 = W + 4\,LiCl$	- 904
$4\,Li + SnCl_4 = Sn + 4\,LiCl$	- 903
$Ge + 4\,BCl = 4\,B + GeCl_4$	- 901
$2\,Pr + C_2Cl_6 = 2\,C + 2\,PrCl_3$	- 901
$4\,Na + VCl_4 = V + 4\,NaCl$	- 895
$Fe + 2\,BCl = 2\,B + FeCl_2$	- 894
$4\,K + CrCl_4 = Cr + 4\,KCl$	- 892
$Sc + 3\,AlCl = 3\,Al + ScCl_3$	- 887
$2\,Ca + VCl_4 = V + 2\,CaCl_2$	- 886
$4\,Zr + 3\,CCl_4 = 3\,C + 4\,ZrCl_3$	- 885
$Sr + 2\,AlCl = 2\,Al + SrCl_2$	- 885
$3\,Li + CrCl_3 = Cr + 3\,LiCl$	- 884
$4\,Nd + 3\,CCl_4 = 3\,C + 4\,NdCl_3$	- 883
$2\,Sc + MoCl_6 = Mo + 2\,ScCl_3$	- 882
$3\,Sr + MoCl_6 = Mo + 3\,SrCl_2$	- 881
$2\,Ba + CCl_4 = C + 2\,BaCl_2$	- 881
$5\,Na + ReCl_5 = Re + 5\,NaCl$	- 880
$2\,Zr + C_2Cl_6 = 2\,C + 2\,ZrCl_3$	- 877
$2\,Nd + C_2Cl_6 = 2\,C + 2\,NdCl_3$	- 876
$3\,Ba + C_2Cl_6 = 2\,C + 3\,BaCl_2$	- 876
$5\,Mg + 2\,MoCl_5 = 2\,Mo + 5\,MgCl_2$	- 876
$3\,Li + VCl_3 = V + 3\,LiCl$	- 876
$5\,Ca + 2\,ReCl_5 = 2\,Re + 5\,CaCl_2$	- 873
$5\,K + NbCl_5 = Nb + 5\,KCl$	- 871
$4\,K + MnCl_4 = Mn + 4\,KCl$	- 868

Table 29 (cont.)

Reaction							Enthalpy, cal/g
Sr	+	2 GeCl	=	2 Ge	+	$SrCl_2$	- 865
Sc	+	3 GeCl	=	3 Ge	+	$ScCl_3$	- 861
4 Na	+	$GeCl_4$	=	Ge	+	4 NaCl	- 858
4 Ti	+	3 CCl_4	=	3 C	+	4 $TiCl_3$	- 857
4 K	+	$MoCl_4$	=	Mo	+	4 KCl	- 856
3 Na	+	$FeCl_3$	=	Fe	+	3 NaCl	- 855
5 Na	+	WCl_5	=	W	+	5 NaCl	- 855
3 Li	+	$GaCl_3$	=	Ga	+	3 LiCl	- 851
Co	+	2 BCl	=	2 B	+	$CoCl_2$	- 851
2 Ca	+	$GeCl_4$	=	Ge	+	2 $CaCl_2$	- 848
2 Ti	+	C_2Cl_6	=	2 C	+	2 $TiCl_3$	- 847
5 Ca	+	2 W Cl_5	=	2 W	+	3 $CaCl_2$	- 847
3 Na	+	$MoCl_3$	=	Mo	+	3 NaCl	- 846
3 Mg	+	2 BCl_3	=	2 B	+	3 $MgCl_2$	- 846
3 Ca	+	2 $FeCl_3$	=	2 Fe	+	3 $CaCl_2$	- 846
5 K	+	$SbCl_5$	=	Sb	+	5 KCl	- 841
Be	+	2 AlCl	=	2 Al	+	$BeCl_2$	- 840
3 Ca	+	2 $MoCl_3$	=	2 Mo	+	3 $CaCl_2$	- 838
2 Li	+	$MoCl_2$	=	Mo	+	2 LiCl	- 837
Ni	+	2 BCl	=	2 B	+	$NiCl_2$	- 837
Na	+	GaCl	=	Ga	+	NaCl	- 836
2 Mg	+	$CrCl_4$	=	Cr	+	2 $MgCl_2$	- 836
2 Li	+	$NiCl_2$	=	Ni	+	2 LiCl	- 835
U	+	4 BCl	=	4 B	+	UCl_4	- 835
6 K	+	WCl_6	=	W	+	6 KCl	- 833
Be	+	2 GeCl	=	2 Ge	+	$BeCl_2$	- 831
Ca	+	2 GaCl	=	2 Ga	+	$CaCl_2$	- 830
2 Mn	+	C_2Cl_4	=	2 C	+	2 $MnCl_2$	- 825
3 Be	+	$MoCl_6$	=	Mo	+	3 $BeCl_2$	- 824
3 Li	+	$AlCl_3$	=	Al	+	3 LiCl	- 823

Table 29 (cont.)

Reaction	Enthalpy, cal/g
$5\ Sr + 2\ MoCl_5 = 2\ Mo + 5\ SrCl_2$	- 821
$2\ Li + CoCl_2 = Co + 2\ LiCl$	- 818
$3\ Li + AuCl_3 = Au + 3\ LiCl$	- 816
$2\ Na + CuCl_2 = Cu + 2\ NaCl$	- 816
$5\ Mg + 2\ NbCl_5 = 2\ Nb + 5\ MgCl_2$	- 811
$3\ Li + SbCl_3 = Sb + 3\ LiCl$	- 810
$2\ Li + FeCl_2 = Fe + 2\ LiCl$	- 809
$In + 3\ BCl = 3\ B + InCl_3$	- 808
$4\ K + SiCl_4 = Si + 4\ KCl$	- 808
$Ca + CuCl_2 = Cu + CaCl_2$	- 806
$5\ K + ReCl_5 = Re + 5\ KCl$	- 806
$4\ Rb + C_2Cl_4 = 2\ C + 4\ RbCl$	- 804
$Y + 3\ GeCl = 3\ Ge + YCl_3$	- 804
$3\ Na + MnCl_3 = Mn + 3\ NaCl$	- 802
$2\ Mg + MnCl_4 = Mn + 2\ MgCl_2$	- 801

(tetrachloroethylene, carbon tetrachloride, and hexachloroethane), chromium tetrachloride, molybdenum hexachloride, and molybdenum pentachloride.

The periodic relationships of the chloride reactions are shown in Figures 21, 22, and 23. It is interesting to compare the general periodic trends, shown by the solid connecting lines, in the chloride, oxide, and fluoride systems. Lithium, which is one of the best reducing agents in the chloride systems, is of moderate efficacy in the oxide and fluoride systems. It occurs at one of the most energetic peaks in the chloride systems. Unlike the oxide systems, magnesium is more energetic than aluminum in the fluoride and chloride systems. Titanium is relatively less energetic in the chloride systems than in the fluoride and oxide systems. The areas including strontium, yttrium, zirconium, the rare earths, hafnium, and tantalum are similar in all three systems.

It is also of interest to compare the trends within the different periodic groups. The trends within each group are similar in all three systems except for the alkaline earths. Thus, most of the groups exhibit less energetic reactions as the atomic number increases. The primary exception to this is the titanium-zirconium-hafnium group, which exhibits an increase in the volumetric energy with increasing atomic number because the lanthanide contraction minimizes the effect of the volume. The behavior of the alkaline earths is therefore striking. Instead of decreasing in energy with increasing atomic number, maximum energy is reached at calcium. This occurs because the heat of formation of the chlorides increases monotonically at a rate which is compensated by the increase in atomic volume and weight when calcium is reached. After calcium, the increase in heat of formation is not enough to overcome the effect of the increase in atomic volume and weight.

The reactions of the chlorides with lithium metal are depicted in Figures 22 and 23. These curves are approximately the inverse of the curves in Figure 21 because the metals that are effective reducing agents form chlorides that are poor oxidizing agents. The chlorides of carbon (hexachloroethane, tetrachloroethylene, and carbon tetrachloride), the transition metal chlorides (vanadium trichloride, chromium trichloride, iron trichloride, cobalt dichloride, nickel dichloride, copper dichloride, molybdenum pentachloride, molybdenum trichloride, tantalum pentachloride, tungsten tetrachloride, tungsten pentachloride, and tungsten hexachloride), gold trichloride, mercury dichloride, lead tetrachloride, and bismuth trichloride are effective oxidizers on a volumetric basis. In general, the higher the oxidation state of the metal in the chloride, the more energetic are its reactions. For instance, note the volumetric outputs of molybdenum di-, tri-, and pentachloride. There are many exceptions, however, such as vanadium tetra- and trichloride and tungsten tetra- and pentachloride.

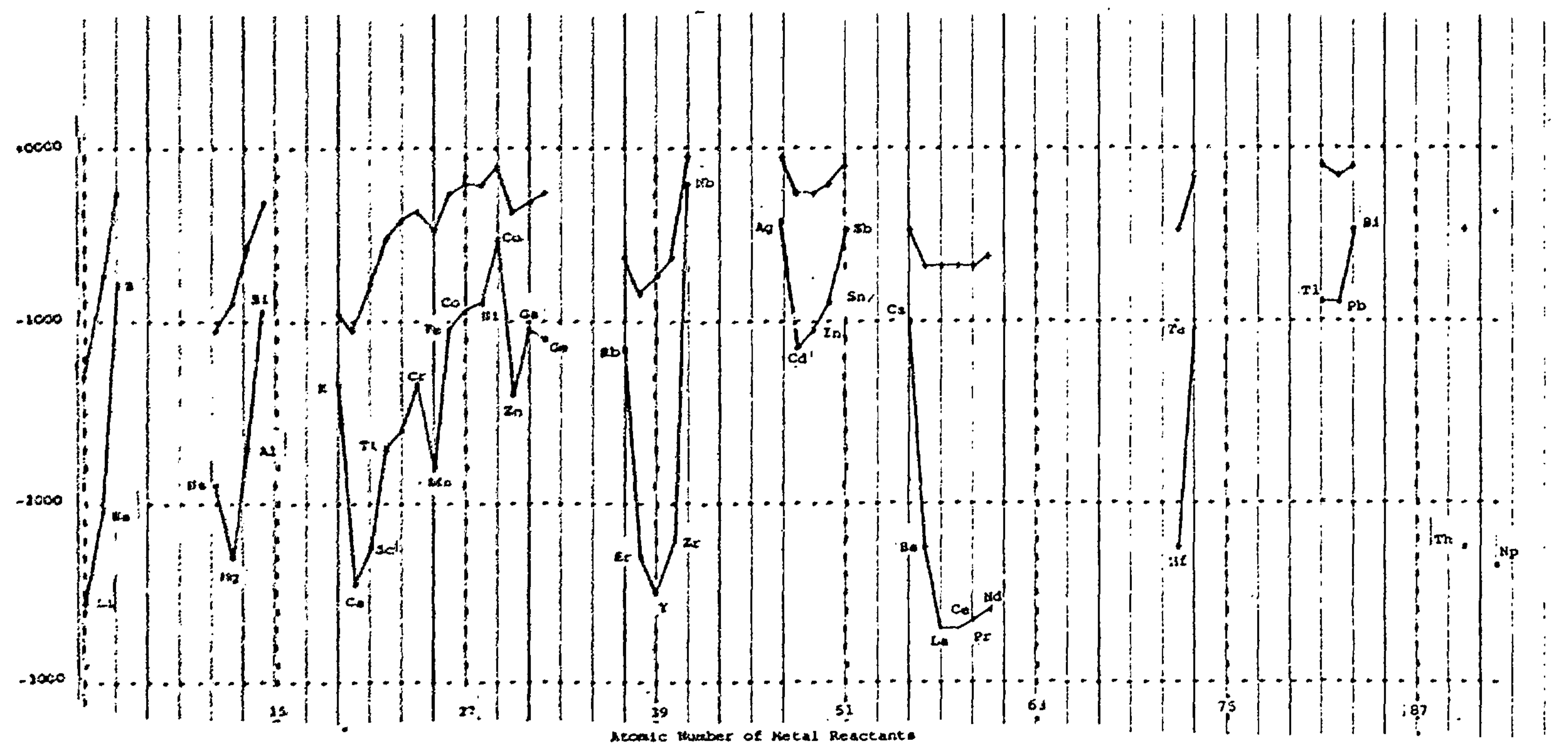


Figure 21

GRAVIMETRIC AND VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH $MoCl_5$

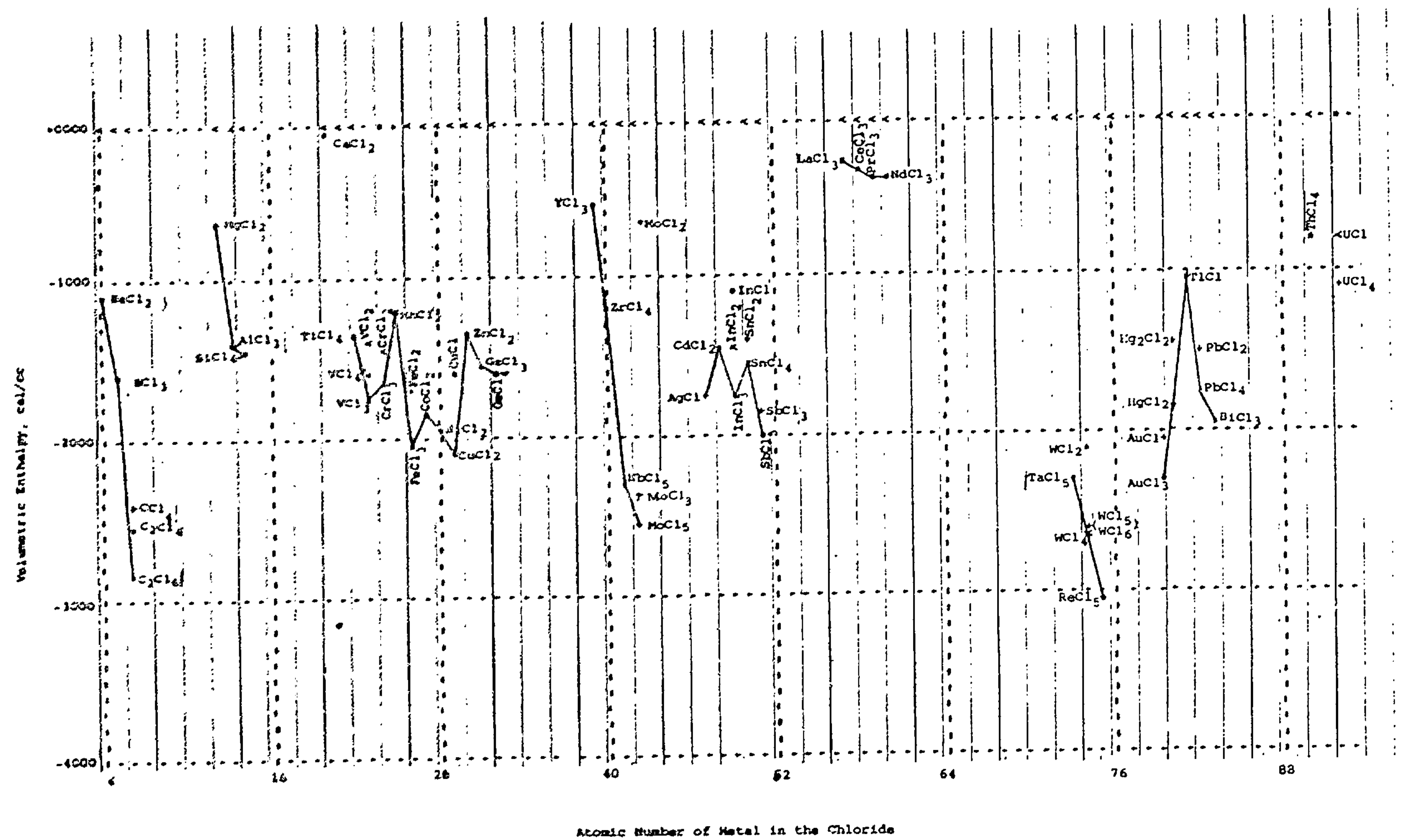


Figure 22

VOLUMETRIC ENTHALPIES OF REACTIONS OF CHLORIDES WITH Li

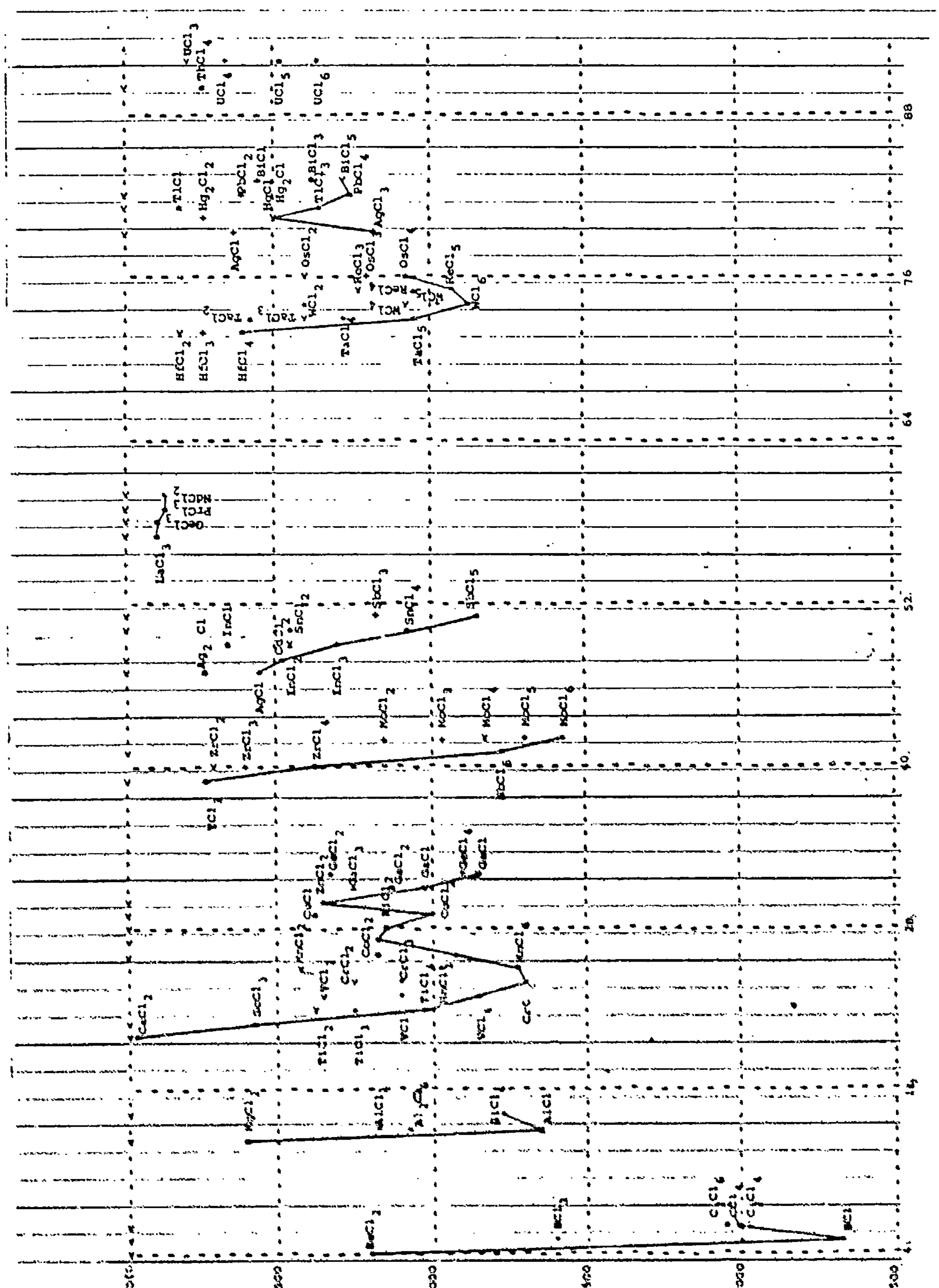


Figure 23

GRAVIMETRIC ENTHALPIES OF REACTIONS OF CHLORIDES WITH Li

The behavior of the chlorides on a gravimetric basis is similar to the volumetric behavior. The chlorides of carbon and the chlorides of many of the transition metals are effective oxidizers. Again, the higher the oxidation state of the metal in the chloride, the more energetic are its reactions. This is illustrated dramatically in Figure 23 by the chlorides of titanium, chromium, manganese, zirconium, molybdenum, indium, tin, antimony, hafnium, tantalum, tungsten, rhenium, osmium, lead, bismuth, and uranium. There are a few exceptions, such as the chlorides of boron, aluminum, gallium, germanium, and mercury. It is interesting that the first three are the first elements in Group IIIA. Evidently, in this group the addition of chloride atoms does not increase the heat of formation of the chloride enough to compensate for the increase in weight of the additional chlorine atoms. Similar charts for the other chlorides and metals indicate similar trends, except for displacement of the vertical scale.

Summaries of the volumetric and gravimetric enthalpies of all the chloride reactions are presented in Tables 30 and 31, respectively. The most energetic reactions are in the upper left-hand corner of the chart. The same trends noted previously are apparent.

Table 30

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH CHLORIDES
(In descending order from top to bottom and left to right)

	$ReCl_5$	C_2Cl_6	WCl_4	WCl_5	WCl_6	$MoCl_5$	C_2Cl_4	CCl_4	$MoCl_3$	$NbCl_5$	$TaCl_5$	$AuCl_3$	WCl_2	$MoCl_2$	$CuCl_2$	$FeCl_3$	AuCl	$SbCl_5$	$BiCl_3$	$NiCl_2$	$HgCl_2$	$CoCl_2$
CE	-3336	-3097	-2807	-2731	-2730	-2670	-2655	-2523	-2521	-2395	-2374	-2349	-2225	-2200	-2144	-2075	-2040	-2020	-1943	-1943	-1856	-1818
LA	-3301	-3025	-2788	-2715	-2714	-2661	-2643	-2513	-2509	-2336	-2365	-2342	-2223	-2196	-2141	-2073	-2039	-2019	-1944	-1943	-1858	-1821
PR	-3249	-2996	-2758	-2692	-2671	-2617	-2609	-2476	-2464	-2311	-2320	-2306	-2182	-2153	-2097	-2024	-2005	-1979	-1898	-1891	-1815	-1769
ND	-3244	-2970	-2724	-2643	-2652	-2598	-2593	-2459	-2444	-2320	-2298	-2288	-2162	-2132	-2076	-1999	-1998	-1968	-1874	-1964	-1703	-1742
LI	-3006	-2814	-2612	-2554	-2553	-2514	-2523	-2408	-2347	-2298	-2270	-2266	-2159	-2134	-2088	-2047	-2009	-1988	-1921	-1918	-1649	-1818
Y	-3178	-2897	-2632	-2558	-2593	-2500	-2514	-2371	-2336	-2208	-2194	-2197	-2055	-2020	-1959	-1865	-1937	-1809	-1747	-1714	-1673	-1592
U	-2986	-2725	-2434	-2348	-2363	-2306	-2368	-2210	-2136	-2008	-1982	-2039	-1873	-1834	-1767	-1646	-1754	-1676	-1546	-1477	-1489	-1360
CA	-2916	-2735	-2529	-2476	-2477	-2432	-2457	-2339	-2307	-2209	-2191	-2201	-2089	-2062	-2014	-1947	-1951	-1921	-1848	-1835	-1781	-1738
HF	-2699	-2655	-2368	-2301	-2302	-2240	-2316	-2157	-2072	-1948	-1921	-1991	-1827	-1781	-1714	-1586	-1715	-1670	-1495	-1419	-1444	-1305
MG	-2672	-2656	-2394	-2336	-2333	-2282	-2343	-2198	-2130	-2015	-1992	-2042	-1805	-1857	-1796	-1691	-1777	-1710	-1594	-1543	-1540	-1435
SC	-2660	-2638	-2368	-2305	-2306	-2248	-2318	-2168	-2090	-1973	-1948	-2008	-1855	-1813	-1749	-1635	-1791	-1665	-1542	-1478	-1489	-1369
TH	-2659	-2629	-2347	-2295	-2287	-2226	-2300	-2148	-2003	-1943	-1917	-1986	-1825	-1781	-1715	-1593	-1716	-1673	-1503	-1429	-1451	-1319
ZR	-2624	-2596	-2304	-2205	-2247	-2185	-2273	-2113	-2019	-1898	-1871	-1951	-1785	-1739	-1671	-1542	-1693	-1593	-1458	-1372	-1408	-1269
BE	-2729	-2490	-2163	-2103	-2104	-2037	-2168	-1989	-1855	-1727	-1696	-1822	-1629	-1572	-1495	-1329	-1557	-1473	-1259	-1131	-1228	-1021
SR	-2682	-2587	-2357	-2314	-2315	-2276	-2324	-2213	-2166	-2092	-2065	-2092	-1985	-1058	-1914	-1646	-1976	-1878	-1764	-1744	-1710	-1660
BA	-2576	-2452	-2283	-2296	-2247	-2210	-2265	-2159	-2108	-2031	-2015	-2048	-1645	-1919	-1877	-1812	-1940	-1809	-1738	-1716	-1688	-1639
PU	-2339	-2198	-1887	-1818	-1823	-1756	-1946	-1766	-1567	-1476	-1415	-1620	-1418	-1356	-1279		-1396	-1287			-1087	
AL	-2278	-2135	-1797	-1756	-1761	-1693	-1900	-1715	-1521	-1409	-1477	-1570	-1357	-1294	-1215	-1023	-1351	-1190	-989	-817	-986	-727
TI	-2229	-2096	-1760	-1791	-1726	-1658	-1672	-1687	-1488	-1379	-1347	-1544	-1333	-1260	-1189	-1005	-1331	-1167	-974	-816	-974	-733
NA	-2185	-2119	-1908	-1923	-1925	-1890	-1980	-1880	-1799	-1735	-1719	-1788	-1690	-1651	-1610	-1534	-1629	-1567	-1484	-1441	-1453	-1378
V	-2092	-1997	-1654	-1693	-1629	-1562	-1793	-1609	-1398	-1295	-1263	-1474	-1262	-1196	-1118	-922	-1276	-1105	-901		-906	
ZN	-1836	-1778	-1459	-1416	-1423	-1357	-1631	-1342	-1196	-1101	-1068	-1319	-1095	-1024	-943	-730	-1146	-952	-720	-523	-751	-451
CR	-1803	-1797	-1391	-1369	-1376	-1307	-1602	-1605	-1140	-1033	-1008	-1280	-1045	-969	-885		-1109	-900				
CD	-1592	-1517	-1192	-1190	-1185	-1125	-1635	-1246	-979	-938	-866	-1142	-919	-845	-767	-551	-1034	-795	-509	-353	-603	-293
GA	-1480	-1481	-1114	-1107	-1115	-1046	-1398	-1193	-843	-797	-760	-1083	-832	-750	-662	-410	-944	-705	-444	-182	-494	-124
K	-1455	-1457	-1395	-1378	-1331	-1307	-1425	-1345	-1250	-1215	-1204	-1296	-1207	-1181	-1151	-1083	-1219	-1144	-1068	-1016	-1063	-992
FE	-1554	-1560	-1088	-1079	-1088	-1010	-1360	-1172	-851	-764	-727	-1061	-805	-720	-631		-924	-678	-410		-464	
TA	-1594	-1418	-1077	-1066	-1075	-1009	-1352	-1156	-857	-776		-1053	-813	-734			-924	-693				
CO	-1371	-1392	-1019	-1006	-1016	-943	-1327	-1114	-777	-692	-654	-1007	-743	-655	-564	-293	-877	-620	-341	-53	-403	
SI	-1364	-1397	-998	-938	-1004	-930	-1322	-1106	-761	-675	-636	-998	-739	-640	-547	-269	-858	-606	-321	-23	-385	
GE	-1433	-1442	-1119	-1109	-1116	-1054	-1374	-1186	-910	-832	-799	-1086	-860	-786	-705	-488	-957	-742	-511		-551	
IN	-1453	-1443	-1004	-1068	-1006	-1030	-1371	-1174	-877	-795	-760	-1069	-829	-750	-667	-429	-937	-708	-460	-216	-506	-165
NI	-1309	-1381	-954	-964	-964	-891	-1288	-1073	-726	-642	-604	-968	-701	-611	-519	-242	-914	-880	-296		-362	
RB	-1258	-1271	-1160	-1156	-1159	-1136	-1257	-1183	-1088	-1059	-1048	-1143	-1058	-1033	-1005	-940	-1093	-1006	-934	-879	-933	-851
B	-1181	-1242	-814	-819	-831	-751	-1209	-875	-572	-488	-444	-870	-574	-472	-371	-51	-756	-456	-132		-220	
SN	-1209	-1250	-933	-932	-941	-841	-1222	-1037	-745	-676	-664	-949	-721	-646	-570	-347	-943	-617	-382		-431	
PB	-1206	-1247	-941	-940	-948	-890	-1220	-1040	-729	-692	-661	-958	-734	-662	-588		-950	-632			-452	
TL	-1090	-1134	-896	-896	-903	-858	-1130	-983	-756	-704	-680	-915	-737	-679	-621		-833	-654			-509	
CS	-1043	-1063	-964	-947	-969	-952	-1066	-1001	-911	-888	-879	-970	-895	-872	-848	-789	-928	-854	-787	-732	-792	-715
SE	-786	-899	-534	-442	-563	-496	-942	-732				-456	-387				-597					
CU	-828	-930	-584	-597	-678	-544	-966	-764	-885	-343	-308	-688	-431	-344			-617	-343				
BI	-793	-968	-533	-550	-561	-493	-951	-736	-344	-280	-291	-657	-382	-287	-197		-597	-292			-84	
AG	-651	-767	-457	-449	-478	-421	-829	-640	-298	-240	-313	-577	-337	-255	-179		-526	-262	-16		-81	
PC	-498	-621					-732	-489				-420					-353					
•	-255	-465					-611	-369				-311					-292					
KE		-426					-583	-331				-272					-259					
GS	-117	-381					-553	-292				-234					-226					
AU		-64					-301	-40														
HG																						
AM	-528	-712	-465	-297	-312	-234	-606	-558	-83			-482	-156	-40			-434	-73				

Table 30 (cont.)

	$SbCl_3$	$BiCl_3$	AgCl	$PbCl_4$	VCl_3	$FeCl_2$	$CrCl_3$	BCl_3	VCl_4	CuCl	$GeCl_4$	$SnCl_4$	$GaCl_3$	$PbCl_2$	$CdCl_2$	Hg_2Cl_2	$SiCl_4$	$CrCl_2$	$InCl_2$	VCl_2	$SnCl_2$	$AlCl_3$
CE	-1605	-1751	-1722	-1693	-1686	-1649	-1602	-1561	-1559	-1558	-1528	-1498	-1463	-1426	-1359	-1378	-1362	-1346	-1339	-1268	-1287	-1245
LA	-1604	-1736	-1725	-1697	-1687	-1636	-1615	-1568	-1566	-1564	-1535	-1506	-1472	-1435	-1370	-1386	-1371	-1358	-1350	-1283	-1299	-1261
PR	-1740	-1481	-1643	-1650	-1629	-1585	-1558	-1526	-1523	-1525	-1404	-1465	-1424	-1387	-1310	-1348	-1320	-1306	-1303	-1223	-1254	-1200
AC	-1741	-1692	-1661	-1635	-1599	-1558	-1528	-1503	-1500	-1501	-1472	-1443	-1390	-1361	-1291	-1328	-1304	-1278	-1277	-1190	-1230	-1166
LI	-1807	-1737	-1736	-1711	-1707	-1662	-1644	-1539	-1598	-1495	-1570	-1544	-1420	-1489	-1436	-1435	-1427	-1426	-1414	-1371	-1365	-1385
F	-1615	-1499	-1537	-1516	-1426	-1407	-1362	-1377	-1371	-1378	-1349	-1322	-1251	-1212	-1133	-1213	-1176	-1117	-1132	-1000	-1094	-969
U	-1429	-1203	-1353	-1341		-1185	-1118	-1196	-1185	-1201	-1179	-1149	-1042	-1002		-1085	-995		-931		-907	
CA	-1757	-1448	-1669	-1667	-1622	-1586	-1503	-1535	-1532	-1532	-1507	-1482	-1449	-1413	-1353	-1378	-1364	-1352	-1346	-1289	-1301	-1271
MF	-1378	-1147	-1310	-1300	-1109	-1136	-1064	-1156	-1144	-1162	-1136	-1112	-1007	-970	-895	-1028	-968	-967	-906	-723	-885	-696
FG	-1482	-1373	-1419	-1399	-1268	-1272	-1216	-1266	-1258	-1270	-1244	-1219	-1134	-1098	-1018	-1125	-1070	-1002	-1028	-878	-999	-945
SC	-1479	-1241	-1363	-1348	-1139	-1264	-1143	-1211	-1201	-1216	-1190	-1166	-1068	-1030	-946	-1075	-1020	-928	-961	-786	-937	-751
IH	-1358	-1235	-1320	-1310	-1129	-1153	-1045	-1169	-1158	-1175	-1149	-1125	-1017	-978	-899	-1036	-978	-870	-910	-717	-689	-677
ZN	-1342	-1142	-1280	-1274	-1090	-1118	-1024	-1139	-1126	-1145	-1121	-1099	-993	-957	-873	-1017	-957	-855	-894	-711	-875	-674
DE	-1151	-879	-1001	-1094	-777	-860	-755	-937	-919	-949	-925	-903	-738	-695	-594	-871	-736	-555	-637	-335	-634	-278
SR	-1649	-1532	-1609	-1591	-1553	-1528	-1504	-1489	-1486	-1487	-1445	-1442	-1409	-1360	-1329	-1350	-1338	-1319	-1315	-1259	-1274	-1243
UA	-1649	-1476	-1564	-1576	-1530	-1516	-1494	-1481	-1479	-1480	-1459	-1436	-1405	-1379	-1331	-1381	-1337	-1322	-1318	-1267	-1282	-1252
PN																						
AL	-408	-579	-860	-874	-467	-595	-409	-721	-699	-739	-718	-704	-501	-460	-342	-653	-536	-316	-417		-434	
II	-698	-497	-856	-869		-611		-726	-706	-743	-723	-707	-522	-463		-660	-552		-442		-456	
NA	-1419	-1315	-1371	-1363	-1276	-1278	-1245	-1273	-1268	-1276	-1259	-1241	-1188	-1105	-1116	-1173	-1145	-1106	-1116	-1039	-1092	-1021
V	-824		-766	-804				-655		-474	-665	-640				-569						
ZN	-868	-709	-838	-864	-182	-346	-243	-514	-488	-536	-517	-507	-477	-238	-117	-479	-344	-89	-210		-242	
CR																						
CO	-522	-148	-694	-530	-38	-207	-83	-390	-363	-413	-399	-390	-155	-118		-375	-234		-97		-136	
GA	-403		-384	-423		-41		-271	-239	-300	-296	-774				-274	-108					
K	-1039	-836	-1012	-1012	-905	-927	-895	-952	-946	-957	-947	-938	-650	-804	-826	-905	-870	-919	-838	-760	-831	-746
FE	-371		-354	-395						-270						-248						
IA																						
CO	-307		-293	-330				-192	-147	-213	-200	-194				-199	-20					
SI	-287		-279	-321				-162	-127	-195	-182	-176				-183						
GF	-460		-449	-484						-567						-335						
IN	-419		-400	-457		-101		-291	-261	-318	-304	-297	-68			-291	-141				-61	
NI	-269		-254	-300				-144	-108	-177	-164	-159				-167						
MO	-909	-809	-849	-893	-781	-806	-774	-847	-830	-843	-834	-827	-768	-753	-719	-802	-765	-711	-732	-655	-729	-641
U	-112		-108	-160						-38	-27	-24				-48						
3L	-350		-337	-273						-265	-253					-246						
PR																						
IF																						
CS	-767	-679	-750	-764	-653	-680	-650	-714	-707	-720	-713	-708	-651	-639	-608	-690	-655	-602	-623	-551	-623	-539
SR																						
CU																						
DI				-49																		
AG	-10			-50																		
PO																						
A																						
RE																						
US																						
AU																						
MG																						
AB																						

Table 30 (cont.)

	$ZnCl_2$	$TiCl_4$	$ZrCl_4$	$MnCl_2$	InCl	$BeCl_2$	UCl_4	TlCl	$ThCl_4$	UCl_3	$MgCl_2$	YCl_3	$NdCl_3$	$CeCl_3$	$LaCl_3$	$PrCl_3$	$CaCl_2$	LiCl	NaCl	$SrCl_2$	RbCl	CsCl
CE	-1219	-1217	-1033	-1035	-986	-914	-885	-916	-567	-561	-365	-281	-73			-30						
LA	-1233	-1229	-1071	-1054	-999	-934	-907	-930	-505	-589	-597	-311	-111	-38		-68						
PR	-1182	-1184	-1014	-997	-901	-876	-846	-890	-532	-527	-532	-251	-42									
ND	-1153	-1159	-981	-984	-940	-843	-811	-867	-494	-490	-293	-215										
LI	-1318	-1306	-1189	-1173	-1084	-1073	-1054	-1030	-702	-782	-625	-536	-389	-321	-286	-351	-76					
Y	-792	-1017	-793	-777	-816	-647	-607	-738	-272	-274	-60											
U		-825			-680																	
CA	-1286	-1241	-1111	-1096	-1035	-896	-974	-974	-713	-705	-546	-402	-308	-242	-208	-271						
HF	-756	-804	-545	-533	-637	-808	-361	-573														
MG	-847	-924	-690	-677	-731	-594	-513	-471	-199	-202												
SC	-812	-854	-600	-587	-692	-450	-413	-411	-89	-92												
TH	-753	-804	-529	-516	-631	-345	-334	-506		-9												
ZR	-746	-794			-631			-508														
BE	-442	-342	-137	-148	-434			-331														
SR	-1424	-1221	-1161	-1088	-1034	-948	-979	-978	-749	-737	-596	-517	-384	-323	-291	-349	-102	-34	-17			
BA	-1233	-1230	-1119	-1107	-1030	-1023	-1006	-948	-749	-780	-649	-571	-452	-402	-382	-419	-260	-222	-192	-153		
NB																						
AL	-213	-343			-278			-170														
TI					-303																	
NA	-1024	-1083	-915	-905	-902	-828	-808	-849	-612	-607	-486	-425	-306	-256	-230	-278	-70	-12				
V																						
ZN		-152			-128			-18														
CR																						
CD		-49			-47																	
GA																						
K	-772	-795	-687	-681	-719	-631	-615	-678	-487	-480	-406	-308	-288	-255	-238	-269	-132	-95	-80	-70	-13	-7
FE																						
TA																						
CO																						
SI																						
GE																						
IN																						
NI																						
RB	-671	-697	-592	-588	-637	-543	-528	-498	-415	-414	-343	-311	-238	-210	-195	-222	-101	-68	-56	-47		
B																						
SN																						
PB																						
TL																						
CS	-570	-598	-501	-497	-524	-460	-446	-418	-353	-353	-292	-207	-205	-182	-169	-192	-91	-63	-53	-46	-5	
SB																						
CU																						
BI																						
AG																						
MO																						
W																						
RE																						
OS																						
AU																						
HG																						
ND																						

Table 31

GRAVIMETRIC ENTHALPIES OF REACTIONS OF METALS WITH CHLORIDES
(in descending order from top to bottom and left to right)

	BCl	C_2Cl_4	CCl_4	C_2Cl_6	$MoCl_6$	AlCl	BCl_3	$MoCl_5$	$CrCl_4$	$NbCl_5$	$MnCl_4$	$MoCl_4$	$SbCl_5$	GeCl	$SiCl_4$	BCl_4	$ReCl_5$	WCl_6	$GeCl_4$	$FeCl_3$	WCl_5
LI	-2316	-2002	-1969	-1093	-1416	-1357	-1349	-1291	-1294	-1224	-1250	-1174	-1149	-1131	-1203	-1146	-1050	-1112	-1076	-1072	-1021
NA	-1787	-1512	-1669	-1098	-1118	-1092	-1045	-1031	-1010	-976	-979	-952	-933	-997	-916	-895	[illegible]	-917	-858	-955	-855
CA	-1818	-1532	-1441	-1442	-1119	-1062	-1043	-1028	-1007	-971	-974	-946	-927	-954	-907	-986	-873	-911	-848	-846	-847
K	-1519	-1293	-1235	-1236	-984	-977	-904	-917	-872	-871	-668	-856	-841	-928	-808	-798	-806	-893	-773	-771	-784
SR	-1382	-1152	-1107	-1042	-861	-865	-792	-821	-741	-776	-766	-767	-753	-865	-704	-791	-739	-750	-682	-681	-708
MG	-1750	-1415	-1359	-1319	-969	-962	-844	-876	-836	-811	-831	-795	-774	-907	-703	-699	-738	-749	-672	-670	-709
SC	-1619	-1290	-1221	-1200	-842	-857	-744	-796	-750	-733	-716	-723	-703	-661	-615	-618	-679	-704	-599	-598	-651
Y	-1368	-1030	-1027	-1016	-769	-790	-758	-713	-667	-750	-694	-656	-649	-804	-654	-602	-627	-645	-540	-549	-603
BE	-1708	-1313	-1229	-1208	-629	-840	-638	-726	-603	-651	-626	-647	-624	-831	-487	-605	-610	-632	-452	-493	-577
BA	-1116	-926	-881	-876	-730	-746	-644	-686	-655	-650	-638	-648	-635	-765	-580	-684	-627	-640	-574	-574	-610
LA	-1225	-902	-934	-911	-745	-764	-638	-690	-652	-646	-632	-644	-637	-774	-558	-604	-620	-615	-558	-553	-599
CE	-1206	-975	-921	-914	-731	-750	-622	-676	-636	-632	-617	-631	-617	-770	-544	-550	-609	-623	-540	-540	-588
PR	-1196	-963	-904	-901	-720	-740	-611	-666	-626	-623	-607	-621	-605	-763	-533	-540	-600	-614	-531	-531	-579
ND	-1169	-938	-885	-876	-770	-724	-590	-648	-606	-594	-588	-604	-591	-750	-513	-542	-595	-598	-513	-513	-564
ZR	-1237	-958	-684	-687	-663	-693	-862	-601	-597	-548	-525	-551	-536	-735	-388	-605	-576	-587	-403	-436	-511
TI	-1264	-934	-857	-832	-593	-680	-374	-621	-450	-457	-492	-467	-489	-705	-282	-311	-462	-469	-315	-316	-433
RB	-975	-804	-763	-746	-682	[illegible]	-558	-600	-574	-572	-555	-573	-564	-659	-305	-511	-542	-570	-506	-506	-545
AL	-1465	-1073	-992	-973	-829		-459	-585	-511	-514	-479	-520	-539	-750	-333	-305	-506	-518	-365	-366	-475
IN	-1150	-825	-748	-791	-549	-566		-680	-410	-425		-436	-427	-664			-435	-440			-409
TH	-928	-704	-652	-638	-513	-530	-396	-671	-425	-430	-408	-438	-426	-628	-328	-346	-437	-441	-347	-347	-418
V	-1126	-735	-719	-778	-506	-556	-320	-687	-370	-349	-354	-363	-347	-647			-407	-410	[illegible]	-273	-380
CS	-720	-559	-554	-453	-463	-504	-408	-455	-427	-430	-417	-435	-425	-564	-372	-380	-435	-437	-360	-380	-422
CR	-1147	-639	-604	-460	-434	-500		-501		-303	-263	-327	-306	-610			-337	-334			-310
HF	-492	-695	-629	-636	-567	-547	-372	-656	-447	-413	-391	-422	-411	-630	-260	-329	-493	-426	-331	-334	-403
ZN	-953	-660	-581	-577	-412	-470	-228	-561	-292	-307	-271	-325	-317	-583	-152	-187	-336	[illegible]	-159	-300	-313
SI	-1197	-773	-657	-640	-347	-400	-136	-525	-220	-279	-191	-278	-255	-614		-67	-334	-268	-94	-97	-270
U	-835	-581	-531	-540	-430	-474	-318	-394	-352	-359	-338	-369	-359	-568	-268	-386	-374	-375	-289	-290	-357
GA	-969	-634	-587	-536	-358	-430	-135	-303	-220	-243	-197	-266	-250	-565	-54	-102	-290	-283	-121	-123	-261
GE	-401	-569	-497	-488	-341	-400		-295	-224	-243	-204	-203	-250				-294	-278		-140	-259
FE	-894	-576	-464	-446	-324	-395		-273	-193	-216	-171	-240	-225	-530			-265	-258			-239
IN	-608	-527	-489	-437	-309	-370	-122	-265	-153	-214	-179	-235	-222	-514	-51	[illegible]	-359	-262	-112	-114	-235
CO	-851	-537	-450	-418	-265	-367	-81	-246	-165	-190	-144	-215	-205	-518	-9	-56	-243	-234	-77	-79	-217
NI	-857	-522	-439	-472	-261	-357	-64	-233	-131	-176	-130	-202	-193	-510		[illegible]	[illegible]	-223	-69	-65	-206
SN	-765	-407	-342	-342	-241	-304		-207	-146	-155	-131	-185	-174	-472			-210	-262	-82	-84	-189
B		-722	-593	-486	-332	-430		-260	-140	-179	-110	-215	-195	-489			-253	-242	[illegible]	-18	-217
CD	-793	-485	-405	-462	-202	-350	-138	-255	-195	-213	-190	-231	-220	-480	-83	-114	-252	-248	-127	-129	-231
NB	-799	-370	-257	-248	-154	-223		-66				-41	-26	-437			-98	-77			-68
SB	-655	-361	-279	-240	-167	-247		-149	-49		-32	-106		-423			-145	-131			-120
TA	-642	-316	-264	-245	-206	-279		-167	-110	-134	-107	-155	-143	-440			-174	-166			-157
BI	-565	-312	-238	-240	-144	-218		-110	-39	-45	-24	-91	-85	-389			-128	-114			-106
PB	-551	-290	-243	-244	-180	-229		-156	-111	-126	-100	-142	-134	-381			-164	-155			-144
CU	-662	-299	-239	-215	-147	-210		-118	-55	-78	-41	-101	-91	-408			-133	-121			-113
MO	-660	-208	-189	-101		-177								-397			-73				
C	-638					-54								-367							
TL	-468	-196	-167	-148	-132	-170		-119	-90	-100	-84	-110	-106	-342			-126	-120			-116
W	-546	-194	-81	-43	-28	-124								-352			-30				
RE	-479	-160	-89	-91	-20	-99								-319							
OS	-443	-171	-89	-91	-10	-100								-311			-16				
AG	-363	-198	-150	-141	-96	-149		-75	-47	-45	-18	-63	-56	-290			-90	-79			-75
HG	-362				-82	-136			-22		-16	-48		-287							
AU	-312	-81	-10	-13		-35								-241							

Table 31 (cont.)

	$MoCl_3$	$MnCl_3$	$CuCl_2$	GaCl	$ReCl_4$	$TaCl_5$	$OsCl_4$	$TiCl_4$	WCl_4	$SnCl_4$	$AuCl_3$	$MoCl_2$	$NiCl_2$	$CrCl_3$	$GaCl_3$	VCl_3	Al_2Cl_6	$CoCl_2$	$AlCl_3$	$SbCl_3$	$OsCl_3$
LI	-1022	-1005	-985	-951	-929	-937	-908	-914	-904	-903	-916	-837	-835	-884	-851	-876	-916	-818	-823	-810	-781
NA	-836	-802	-816	-830	-794	-784	-775	-758	-770	-745	-715	-716	-688	-704	-690	-696	-766	-674	-635	-684	-653
CA	-838	-790	-806	-830	-783	-778	-766	-793	-751	-732	-705	-705	-674	-688	-675	-690	-688	-660	-614	-671	-672
K	-778	-724	-748	-764	-730	-724	-722	-685	-716	-696	-675	-670	-639	-645	-637	-639	-641	-627	-583	-640	-644
SR	-695	-634	-670	-724	-667	-649	-654	-593	-648	-609	-617	-605	-563	-560	-557	-554	-548	-552	-493	-571	-598
MG	-691	-607	-646	-730	-652	-628	-637	-534	-629	-570	-593	-572	-506	-490	-492	-490	-461	-490	-376	-524	-555
SC	-630	-537	-596	-687	-603	-572	-587	-480	-579	-512	-552	-524	-449	-423	-431	-414	-386	-434	-306	-474	-514
Y	-593	-499	-554	-647	-560	-535	-592	-433	-548	-492	-526	-497	-429	-405	-412	-397	-373	-416	-308	-452	-492
BE	-548	-420	-409	-639	-533	-467	-515	-314	-506	-410	-469	-445	-337	-284	-306	-271	-215	-320	-117	-381	-446
BA	-595	-539	-575	-642	-562	-561	-572	-499	-566	-524	-549	-531	-487	-476	-478	-471	-461	-478	-418	-499	-523
LA	-581	-511	-547	-639	-567	-541	-555	-459	-548	-496	-531	-507	-451	-433	-438	-427	-410	-440	-357	-469	-501
CE	-570	-499	-533	-637	-557	-530	-545	-445	-538	-484	-522	-497	-439	-421	-426	-418	-396	-428	-344	-458	-493
PR	-561	-489	-517	-633	-549	-522	-538	-432	-530	-475	-516	-493	-431	-411	-417	-405	-386	-420	-333	-451	-486
ND	-546	-477	-521	-611	-536	-567	-524	-410	-517	-460	-504	-477	-416	-395	-402	-398	-369	-405	-317	-437	-474
ZR	-497	-384	-448	-577	-483	-444	-470	-297	-451	-360	-455	-415	-331	-280	-294	-273	-250	-303	-189	-365	-420
TI	-339	-262	-345	-528	-400	-353	-394		-392	-274	-388	-332	-210		-183		-93	-203		-265	-348
RB	-531	-479	-512	-580	-529	-562	-515	-437	-510	-466	-500	-479	-435	-419	-423	-415	-402	-425	-365	-448	-476
AL	-441	-298	-468	-564	-443	-369	-628	-187	-416	-307	-417	-361	-239	-170	-200	-152		-223		-293	-374
MN	-379		-349	-502	-389	-339	-376		-366		-374	-321					-98				-337
TH	-395	-309	-372	-491	-401	-368	-391	-250	-393	-314	-388	-349	-272	-238	-252	-231	-201	-265	-154	-304	-358
V	-347	-218	-317	-482	-362	-308	-350		-339	-236	-351	-293					-48			-232	-313
CS	-408	-358	-344	-472	-411	-358	-405	-343	-400	-358	-401	-376	-332	-315	-342	-312	-298	-326	-271	-349	-381
CR	-274	-137	-243	-439	-300	-238	-287		-274		-297	-231									-258
HF	-340	-208	-338	-453	-388	-350	-378	-242	-370	-258	-376	-335	-259	-194	-207	-189	-186	-249	-127	-291	-347
ZN	-278	-150	-241	-425	-304	-246	-291	-60	-279	-175	-300	-238	-122	-56	-86	-47		-110		-177	-263
SI	-222	-74	-143	-421	-261	-181	-247		-231	-78	-266	-179	-6							-93	-219
U	-336	-257	-316	-429	-340	-311	-338	-248	-331	-265	-341	-301	-230	-197	-211		-164	-222		-260	-314
GA	-222	-66	-190		-254	-187	-242		-229	-104	-200	-185	-46					-32		-114	-219
GE	-224	-97	-197	-381	-253	-194	-243		-231		-258	-192								-129	-221
FE	-200	-89	-149	-373	-234	-168	-223		-210		-242	-165								-99	-203
IN	-198	-64	-172	-361	-231	-171	-220		-209	-98	-239	-170	-46		-15			-36		-108	-202
CO	-177	-24	-147	-355	-214	-147	-203		-190	-66	-225	-149	-12							-80	-186
NI	-166	-13	-176	-347	-204	-136	-193		-180	-54	-216	-139								-69	-177
SN	-158	-45	-135	-308	-189	-135	-181		-170		-201	-135								-83	-169
B	-168		-123	-359	-218	-124	-200		-193	-11	-228	-130								-36	-178
CD	-200	-89	-177	-343	-221	-176	-219	-10	-208	-114	-235	-175	-72	-14	-40	-7		-62		-121	-203
NB	-15			-259	-79		-68		-52		-113	-9									-68
SB				-270	-122		-116		-104		-148										-110
TA	-131	-40		-292	-163		-155		-143		-172	-117									-146
BI	-69		-85	-247	-111	-88	-103		-91		-134	-59									-99
PB	-124	-34	-107	-288	-150	-107	-186		-136		-163	-111									-137
CU	-92			-265	-116	-60	-110		-99		-138	-69									-105
MO				-223	-58		-49				-91										-50
C				-160																	
TL	-100	-47	-49	-213	-118	-90	-114		-109		-129	-93									-112
W				-187	-24		-17				-49										-20
RE				-161			-9				-98										-14
OS				-163	-7						-44										
AG	-49		-32	-184	-80	-35	-75		-66		-100	-45								-1	-74
HG				-177	-60		-62														-62
AU				-107																	

Table 31 (cont.)

	$ReCl_3$	$FeCl_2$	$PbCl_4$	$GaCl_2$	$BiCl_4$	$TaCl_4$	$CrCl_2$	$BeCl_2$	$TiCl_3$	$InCl_3$	$TlCl_3$
LI	-769	-800	-734	-740	-715	-715	-737	-779	-731	-680	-630
NA	-671	-644	-632	-624	-616	-609	-603	-559	-580	-573	-555
CA	-640	-640	-619	-598	-607	-595	-585	-564	-559	-556	-542
K	-677	-618	-598	-540	-544	-577	-565	-544	-543	-544	-534
SR	-597	-543	-537	-510	-520	-514	-491	-491	-461	-378	-481
MG	-581	-575	-484	-444	-457	-449	-399	-298	-341	-394	-421
SC	-407	-419	-441	-393	-420	-403	-344	-226	-320	-347	-384
Y	-479	-463	-425	-364	-411	-372	-340	-245	-297	-343	-377
BE	-430	-370	-355	-294	-337	-308	-210		-109	-234	-304
BA	-517	-449	-475	-451	-469	-453	-420	-383	-397	-421	-434
LA	-467	-499	-444	-414	-431	-416	-370	-305	-336	-375	-399
CE	-401	-417	-434	-364	-427	-406	-365	-295	-323	-365	-391
PR	-473	-540	-427	-391	-415	-398	-350	-245	-314	-357	-385
ND	-442	-476	-415	-370	-403	-386	-342	-248	-299	-344	-374
ZR	-404	-291	-331	-241	-337	-304	-235		-130	-298	-308
TI	-331	-196	-250	-150	-241	-210				-145	-227
RB	-449	-417	-450	-407	-420	-402	-370	-232	-349	-377	-395
AL	-357	-242	-273	-194	-222	-227	-115		-6	-152	-243
IN	-3[illegible]			-180	-240	-209			-33		-276
TH	-364	-241	-2[illegible]4	-283	-283	-261	-290	-103	-140	-316	-247
V	-294		-226	-156	-212	-178					-201
CS	-3[illegible]	-319	-342	-334	-335	-320	-204	-244	-263	-293	-319
CR	-287			-73	-151	-115					-149
HF	-338	-318	-292	-231	-27[illegible]	-249	-107	-87	-135	-204	-257
ZN	-244	-93	-170	-94	-163	-129	-45			-64	-159
SI	-2[illegible]		-103		-87	-37					-42
U	-30[illegible]	-211	-255	-207	-145	-226			-122	-184	-255
GA	-207	-12	-120		-166	-45					-109
GE	-204		-133	-40	-120	-85					-131
FE	-184		-106	-7	-92	-52					-97
MN	-187	-21	-113	-20	-161	-65					-104
CO	-1[illegible]		-45		-74	-35					-82
NI	-16[illegible]		-[illegible]		-66	-24					-73
SN	-154		-90	-13	-80	-48					-84
B	-150		-53		-34						-50
CD	-189	-88	-125	-51	-111	-64				-28	-115
MO	-44										
SB	-43				-3						-17
TA	-133			-15	-70						-74
BI	-88		-10								-13
PB	-127			-10	-67	-43					-72
CU	-92				-18						-25
H	-37										
C											
TL	-108			-32	-65	-49					
W	-8										
RE											
OS											
AG	-65		-7		-2						-11
HG	-51				-5						-18
AU											

	$OsCl_2$	WCl_2	$CuCl$	$BiCl_3$	$GeCl_2$	UCl_6	VCl_2	$ZnCl_2$	$TiCl_2$	$ZrCl_4$
LI	-594	-585	-618	-602	-669	-637	-643	-639	-613	-616
NA	-535	-526	-541	-530	-561	-538	-527	-532	-500	-501
CA	-524	-515	-527	-517	-544	-521	-506	-513	-478	-478
K	-519	-511	-521	-512	-533	-514	-501	-507	-478	-479
SR	-475	-467	-467	-451	-467	-450	-429	-440	-406	-406
MG	-425	-413	-400	-396	-377	-358	-310	-336	-275	-272
SC	-395	-383	-363	-361	-329	-312	-258	-287	-223	-210
Y	-388	-377	-358	-356	-328	-313	-267	-292	-238	-235
BE	-334	-319	-219	-232	-211	-197	-109	-157	-64	-58
BA	-435	-427	-420	-417	-411	-390	-376	-387	-357	-356
LA	-400	-396	-363	-390	-363	-340	-315	-333	-291	-290
CE	-394	-389	-374	-372	-352	-327	-304	-322	-280	-278
PR	-393	-383	-366	-366	-344	-331	-295	-314	-271	-270
ND	-384	-374	-357	-356	-331	-310	-282	-301	-258	-256
ZR	-331	-318	-278	-228	-238	-224	-173	-200	-147	
TI	-260	-251	-201	-207	-125	-117				
RB	-404	-[illegible]94	-303	-331	-368	-358	-334	-346	-316	-315
AL	-282	-266	-214	-220	-128	-118		-73		
IN	-263	-2.9			-127	-119			-7	
TH	-293	-281	-248	-251	-262	-194	-145	-170	-121	-119
V	-243	-228	-175	-192	-92	-85				
CS	-332	-324	-307	-307	-285	-279	-255	-267	-241	-240
CR	-199	-190			-73	-18				
HF	-264	-272	-238	-241	-190	-182	-133	-144	-109	-101
ZN	-206	-191	-132	-181	-44	-30				
SI	-161	-145	-57	-71						
U	-264	-251	-217	-221	-172				-100	
GA	-167	-151	-78	-90						
GE	-173	-158	-94	-101						
FE	-156	-140	-67	-70						
MN	-158	-143	-77	-87						
CO	-143	-126	-52	-64						
NI	-136	-119	-43	-56						
SN	-135	-122	-60	-70						
B	-129	-109	-11	-28						
CD	-163	-149	-92	-101	-11	-8				
MO	-46	-27								
SB	-34	-68								
TA	-117	-107								
BI	-76	-61								
PB	-114	-103								
CU	-83	-69								
H	-34									
C										
TL	-96	-90			-14	-12				
W	-13									
RE	-6									
OS										
AG	-60	-48		-2						
HG	-49									
AU										

Table 31 (cont.)

	$TaCl_3$	$SnCl_2$	$InCl_2$	$MnCl_2$	HgCl	$HgCl_2$	$CdCl_2$	UCl_5	BiCl	AgCl	$TaCl_2$	AuCl	$PbCl_2$	$ScCl_3$	$HfCl_4$	$ZrCl_3$	$MgCl_2$	InCl	UCl_4	Hg_2Cl_2
LI	-577	-549	-548	-573	-480	-491	-519	-433	-431	-448	-415	-372	-375	-419	-390	-389	-384	-338	-342	-271
NA	-508	-479	-473	-477	-452	-445	-451	-431	-407	-405	-374	-351	-341	-335	-334	-325	-304	-310	-300	-256
CA	-440	-463	-457	-456	-445	-435	-434	-412	-399	-395	-359	-342	-327	-303	-312	-298	-270	-296	-279	-247
K	-448	-465	-460	-454	-447	-436	-441	-423	-405	-404	-373	-352	-343	-341	-330	-331	-316	-315	-308	-243
SR	-444	-412	-400	-387	-421	-398	-347	-367	-380	-366	-332	-327	-306	-269	-284	-270	-243	-280	-260	-240
MG	-355	-329	-317	-253	-389	-332	-290	-254	-340	-297	-247	-278	-223	-49	-140	-94		-198	-129	-181
SC	-418	-287	-280	-208	-368	-305	-254	-215	-324	-273	-220	-263	-199		-103	-52		-176	-98	-147
Y	-316	-293	-284	-222	-366	-300	-261	-229	-324	-275	-229	-266	-209	-56	-132	-93	-20	-187	-124	-175
BE	-397	-198	-184	-51	-333	-239	-152	-99	-288	-205	-142	-242	-126					-107		-122
BA	-391	-373	-367	-342	-399	-306	-351	-331	-362	-341	-309	-313	-268	-244	-262	-248	-224	-266	-244	-233
LA	-398	-320	-319	-274	-378	-331	-299	-273	-338	-333	-263	-284	-242	-147	-190	-165	-118	-220	-177	-199
CE	-339	-317	-310	-265	-374	-324	-291	-269	-334	-296	-250	-260	-235	-125	-161	-154	-106	-214	-169	-194
PR	-333	-311	-304	-257	-370	-319	-254	-257	-331	-291	-251	-277	-231	-126	-178	-147	-97	-210	-162	-191
ND	-372	-300	-293	-244	-305	-311	-273	-246	-326	-298	-242	-272	-223	-113	-163	-135	-84	-203	-153	-196
ZR	-245	-218	-210		-331	-251	-159	-156	-291	-223	-174	-231	-140		-60			-142		-184
TI	-155	-127	-110		-293	-184		-22	-252	-159	-96	-187	-36					-71		-97
RB	-350	-338	-333	-304	-379	-340	-318	-299	-344	-317	-283	-297	-267	-215	-236	-221	-196	-247	-222	-221
AL	-162	-131	-117		-303	-192	-98	-32	-260	-164	-95	-194	-44					-68		-96
MN	-156				-290	-184		-47	-251		-98	-189								
TH	-214	-192	-184	-112	-306	-245	-165	-133	-270	-203	-150	-216	-143		-54	-15		-128	-55	-134
V	-139				-279	-104		-18	-239	-140	-75	-176								-85
CS	-244	-279	-260	-238	-331	-262	-253	-236	-302	-264	-232	-260	-222	-163	-186	-171	-148	-208	-178	-194
CR	-73				-252				-214		-31	-130								
HF	-203	-166	-159	-97	-301	-217	-143	-123	-205	-195	-140	-210	-129			-20		-116	-52	-125
ZN	-88	-61	-50		-255	-131	-25		-217	-109	-45	-135	-39					-28		-67
SI					-235	-75			-194	-52		-144								-27
U	-146	-167	-160		-285	-202			-252	-142	-130	-200	-128		-45	-11		-115		-124
GA	-39				-234	-89			-196	-68		-130								-39
GE	-50				-234	-101			-198	-31	-15	-136								-48
FE	-19				-226	-80			-188	-60		-124								-34
IN	-93	-12			-225	-87			-189	-45	-8	-126								-40
CO	-4				-218	-66			-181	-49		-116								-27
NI					-213	-62			-176	-42		-112								-22
SN	-22				-205	-73			-172	-55		-114								-34
B					-218	-41			-177	-20		-105								-6
CD	-53	-31	-20		-224	-96			-190	-83	-21	-131	-18					-9		-30
NB					-164				-128			-58								
SB					-178				-148			-60								
TA					-193				-160			-105								
BI					-169	-13						-75								
PB	-23				-182	-04			-154		-1	-102								
CU					-170				-139			-80								
MO					-151				-117			-50								
C					-114				-76											
TL	-35				-154	-63			-132		-19	-92								
W					-132				-98			-32								
RE					-121				-51			-30								
OS					-125				-91			-27								
AG					-143	-11			-116			-04								
HG									-110											
AU					-99				-64											

Table 31 (cont.)

	Ag_2Cl	$ZrCl_2$	$HfCl_3$	YCl_3	$ThCl_4$	UCl_3	TlCl	$HfCl_2$	$NdCl_3$	$PrCl_3$	$CeCl_3$	$LaCl_3$	$CaCl_2$	LiCl	NaCl	$SrCl_2$	$BaCl_2$	RbCl	CsCl
LI	-258	-286	-271	-20[illegible]	-263	-219	-197	-191	-142	-131	-122	-110	-43						
NA	-245	-247	-239	-226	-231	-197	-187	-174	-126	-116	-109	-98	-41	-8					
[illegible]	-236	-222	-217	-196	-209	-177	-177	-155	-98	-88	-80	-70							
K	-252	-263	-254	-248	-248	-215	-197	-193	-158	-150	-14[illegible]	-134	-96	-79	-60	-43	-9	-7	-3
SR	-230	-212	-208	-190	-202	-176	-176	-157	-111	-103	-97	-88	-40	-15	-7				
MG	-173	-45	-62		-51	-44	-109	-30											
SC	-160	-11	-32		-21	-20	-96	-7											
Y	-168	-52	-66		-56	-50	-108	-37											
BE	-118						-49												
BA	-224	-202	-200	-185	-194	-173	-174	-156	-118	-111	-110	-105	-82	-73	-65	-55			
LA	-191	-120	-126	-86	-118	-104	-135	-89	-23	-15	-8								
CE	-187	-111	-118	-76	-110	-97	-131	-93	-15	-6									
PR	-184	-104	-112	-68	-104	-92	-128	-79	-8										
ND	-179	-94	-103	-57	-95	-84	-124	-79											
ZR	-140		-17				-82	0											
TI	-94																		
RB	-215	-182	-182	-165	-176	-159	-165	-144	-107	-101	-96	[illegible]	-56	-40	-32	-23	+		
AL	-94						-25												
MN	-95																		
TH	-130		-8			-1	-74												
V	-83																		
CS	-159	-144	-147	-127	-142	-131	-146	-120	-86	-81	-77	-72	-45	-33	-27	-21	-3	-2	
CR	-59																		
HF	-125						-71												
ZN	-66						-2												
SI	-28																		
U	-121		-5																
GA	-39																		
GE	-49																		
FE	-35																		
IN	-41																		
CO	-28																		
NI	-20																		
SN	-35																		
B	-9																		
CD	-50																		
NB																			
SB																			
TA	-33																		
BI																			
PB	-33																		
CU	-4																		
MO																			
C																			
TL	-39																		
W																			
RE																			
OS																			
AG																			
HG	-1																		
AU																			

J. Chromate Reactions

The reactions between 49 metals and 5 chromates were programmed on the computer. A total of 2920 possible reactions was examined, and 114 of these were printed. As mentioned previously, when two reactants undergo more than one reaction, only the most energetic one is printed. The reactions with positive enthalpies are also discarded. The chromates are the least energetic of the oxide systems examined. The most energetic reaction exhibits an enthalpy of only -3845 cal/cc.

Representative computer data for a few of the chromate reactions are illustrated in Table 32. The relatively low energies of these reactions are due primarily to the high heat of formation of the chromates. The high heats of formation of the product oxides partially compensate for this.

The periodic variation of the enthalpies of the reactions of the metals with lead chromate is shown in Figure 24. The trends are the same as those observed in the other oxide systems. The Group II metals (beryllium, magnesium, and calcium), the Group IVB metals (titanium, zirconium, and hafnium) and the rare earths (lanthanum, cerium, praseodymium, neodymium, samarium, gadolinium, terbium, holmium, erbium, thorium, uranium, and neptunium) are effective reducing agents. With the exception of Group IVB, which is anomalous because of the lanthanide contraction, the energies within a group tend to decrease with increasing atomic number. This is apparent in Group IA (lithium, rubidium, and cesium), Group IIA (beryllium, magnesium, strontium, and barium), Group VB (vanadium, niobium, and tantalum), and Group VIB (chromium, nolybdenum, and tungsten). Except for displacement of the vertical scale, the other chromates exhibit similar trends.

The most energetic chromate reactions are listed in Tables 33 and 34. A summary of the enthalpies of all the chromate reactions is presented in Tables 35 and 36. The trends described previously are evident in Tables 35 and 36. Lead and silver chromate are the most effective oxidizers on a volumetric basis, and sodium and lead chromate are the most effective on a gravimetric basis.

Table 32

DATA ON REACTIONS OF VARIOUS METALS WITH CHROMATES

	3 Ge	+ 4 Ag_2CrO_4	= 4 Ag_2O	+ 3 GeO_2	+ 2 Cr_2O_3
Heat of formation		-170.15	-7.31	-128.30	-269.70
Molecular weight	72.60	331.70	231.76	104.60	152.02
Density	5.35	5.63	7.14	4.70	5.21
Melting point, °C	960.00		300.00	1000.00	2265.00
Boiling point, °C	2700.00				
Heat of reaction, kcal	-272.92				
Reactants' density	5.58				
Gravimetric enthalpy, cal/g	-176.66				
Volumetric enthalpy, cal/cc	-986.58				

	3 Hf	+ 4 Ag_2CrO_4	= 4 Ag_2O	+ 3 HfO_2	+ 2 Cr_2O_3
Heat of formation		-170.15	-7.31	-271.50	-269.70
Molecular weight	178.50	331.77	231.76	210.60	152.02
Density	13.30	5.63	7.14	9.68	5.21
Melting point, °C	2227.00		300.00	2810.00	2265.00
Boiling point, °C	3200.00				
Heat of reaction, kcal	-702.52				
Reactants' density	6.74				
Gravimetric enthalpy, cal/g	-377.18				
Volumetric enthalpy, cal/cc	-2543.64				

	2 Ho	+ 2 Ag_2CrO_4	= 2 Ag_2O	+ Ho_2O_3	+ Cr_2O_3
Heat of formation		-170.15	-7.31	-449.60	-269.70
Molecular weight	164.94	331.77	231.76	377.88	152.02
Density	8.76	5.63	7.14		5.21
Melting point, °C			300.00		2265.00
Boiling point, °C					
Heat of reaction, kcal	-393.61				
Reactants' density	6.38				
Gravimetric enthalpy, cal/g	-396.22				
Volumetric enthalpy, cal/cc	-2529.31				

Table 32 (cont.)

	2 La	+ 2 Ag_2CrO_4	= 2 Ag_2O	+ La_2O_3	+ Cr_2O_3
Heat of formation		-170.15	-7.31	-458.00	-269.70
Molecular weight	138.92	331.77	231.76	325.84	152.02
Density	6.15	5.63	7.14	6.51	5.21
Melting point, °C	880.00		300.00	2315.00	2265.00
Boiling point, °C	1800.00			4200.00	
Heat of reaction, kcal	-402.01				
Reactants' density	5.77				
Gravimetric enthalpy, cal/g	-427.05				
Volumetric enthalpy, cal/cc	-2464.22				

	6 Li	+ 2 Ag_2CrO_4	= 2 Ag_2O	+ 3 Li_2O	+ Cr_2O_3
Heat of formation		-170.15	-7.31	-142.40	-269.70
Molecular weight	6.94	331.77	231.76	29.88	152.02
Density	.53	5.63	7.14	2.01	5.21
Melting point, °C	180.00		300.00	1700.00	2265.00
Boiling point, °C	1326.00				
Heat of reaction, kcal	-371.21				
Reactants' density	3.60				
Gravimetric enthalpy, cal/g	-526.41				
Volumetric enthalpy, cal/cc	-1894.52				

	3 Mg	+ 2 Ag_2CrO_4	= 2 Ag_2O	+ 3 MgO	+ Cr_2O_3
Heat of formation		-170.15	-7.31	-143.84	-269.70
Molecular weight	24.32	331.77	231.76	40.32	152.02
Density	1.74	5.63	7.14	3.58	5.21
Melting point, °C	650.00		300.00	2800.00	2265.00
Boiling point, °C	1120.00				
Heat of reaction, kcal	-375.53				
Reactants' density	4.61				
Gravimetric enthalpy, cal/g	-509.89				
Volumetric enthalpy, cal/cc	-2348.64				

Table 32 (cont.)

	8 La	+ 6 $PbCrO_4$	= 3 Pb_2O	+ 4 La_2O_3	+ 3 Cr_2O_3
Heat of formation		-217.70	-51.20	-458.00	-269.70
Molecular weight	138.92	323.22	430.42	325.84	152.02
Density	6.15	6.30	8.34	6.51	5.21
Melting point, °C	880.00	844.00		2315.00	2265.00
Boiling point, °C	1800.00			4200.00	
Heat of reaction, kcal	-1488.50				
Reactants' density	6.24				
Gravimetric enthalpy, cal/g	-487.92				
Volumetric enthalpy, cal/cc	-3046.85				

	8 Li	+ 2 $PbCrO_4$	= Pb_2O	+ 4 Li_2O	+ Cr_2O_3
Heat of formation		-217.70	-51.20	-142.40	-269.70
Molecular weight	6.94	323.22	430.42	29.88	152.02
Density	.53	6.30	8.34	2.01	5.21
Melting point, °C	180.00	844.00		1700.00	2265.00
Boiling point, °C	1326.00				
Heat of reaction, kcal	-455.10				
Reactants' density	3.40				
Gravimetric enthalpy, cal/g	-648.33				
Volumetric enthalpy, cal/cc	-2203.03				

	4 Mg	+ 2 $PbCrO_4$	= Pb_2O	+ 4 MgO	+ Cr_2O_3
Heat of formation		-217.70	-51.20	-143.84	-269.70
Molecular weight	24.32	323.22	430.42	40.32	152.02
Density	1.74	6.30	8.34	3.58	5.21
Melting point, °C	650.00	844.00		2800.00	2265.00
Boiling point, °C	1120.00				
Heat of reaction, kcal	-460.86				
Reactants' density	4.69				
Gravimetric enthalpy, cal/g	-619.67				
Volumetric enthalpy, cal/cc	-2907.31				

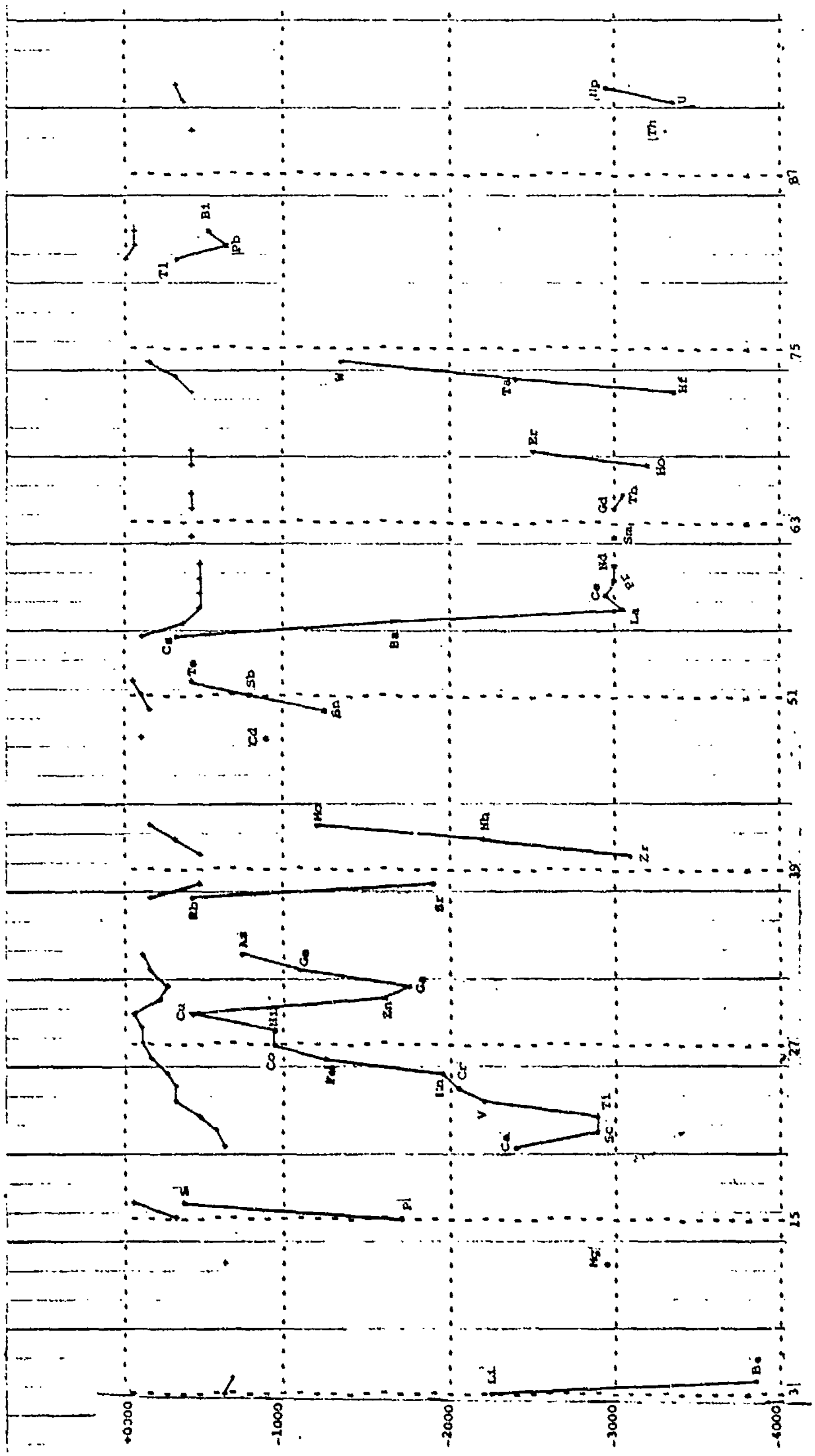


Figure 24

GRAVIMETRIC AND VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH $PbCrO_3$

Table 33

MOST ENERGETIC CHROMATE AND DICHROMATE REACTIONS WITH METALS, IN TERMS OF VOLUMETRIC ENTHALPY

Reaction	Enthalpy, cal/cc
$4\ Be + 2\ Pb(CrO_4) = Pb_2O + 4\ BeO + Cr_2O_3$	-3845
$2\ U + 2\ Pb(CrO_4) = Pb_2O + 2\ UO_2 + Cr_2O_3$	-3322
$2\ Hf + 2\ Pb(CrO_4) = Pb_2O + 2\ HfO_2 + Cr_2O_3$	-3310
$2\ Th + 2\ Pb(CrO_4) = Pb_2O + 2\ ThO_2 + Cr_2O_3$	-3259
$8\ Ho + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Ho_2O_3 + 4\ Ho_2O_3$	-3173
$2\ Zr + 2\ Pb(CrO_4) = Pb_2O + 2\ ZrO_2 + Cr_2O_3$	-3065
$8\ Tb + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Tb_2O_3 + 3\ Cr_2O_3$	-3048
$8\ La + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ La_2O_3 + 3\ Cr_2O_3$	-3046
$8\ Sm + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Sm_2O_3 + 3\ Cr_2O_3$	-2999
$8\ Nd + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Nd_2O_3 + 3\ Cr_2O_3$	-2998
$8\ Gd + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Gd_2O_3 + 3\ Cr_2O_3$	-2986
$8\ Pr + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Pr_2O_3 + 3\ Cr_2O_3$	-2980
$8\ Ce + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Ce_2O_3 + 3\ Cr_2O_3$	-2939
$2\ Np + 2\ Pb(CrO_4) = Pb_2O + 2\ NpO_2 + Cr_2O_3$	-2914
$4\ Mg + 2\ Pb(CrO_4) = Pb_2O + 4\ MgO + Cr_2O_3$	-2907
$3\ Be + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ BeO + Cr_2O_3$	-2881
$8\ Sc + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Sc_2O_3 + 3\ Cr_2O_3$	-2879
$8\ Ti + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Ti_2O_3 + 3\ Cr_2O_3$	-2861
$3\ Th + 4\ Ag_2(CrO_4) = 4\ Ag_2O + 3\ ThO_2 + 2\ Cr_2O_3$	-2563
$3\ U + 4\ Ag_2(CrO_4) = 4\ Ag_2O + 3\ UO_2 + 2\ Cr_2O_3$	-2546
$3\ Hf + 4\ Ag_2(CrO_4) = 4\ Ag_2O + 3\ HfO_2 + 2\ Cr_2O_3$	-2543
$2\ Ho + 2\ Ag_2(CrO_4) = 2\ Ag_2O + Ho_2O_3 + Cr_2O_3$	-2529
$8\ Er + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Er_2O_3 + 3\ Cr_2O_3$	-2499
$2\ La + 2\ Ag_2(CrO_4) = 2\ Ag_2O + La_2O_3 + Cr_2O_3$	-2464
$2\ Tb + 2\ Ag_2(CrO_4) = 2\ Ag_2O + Tb_2O_3 + Cr_2O_3$	-2439
$2\ Nd + 2\ Ag_2(CrO_4) = 2\ Ag_2O + Nd_2O_3 + Cr_2O_3$	-2415
$2\ Pr + 2\ Ag_2(CrO_4) = 2\ Ag_2O + Pr_2O_3 + Cr_2O_3$	-2408
$2\ Sm + 2\ Ag_2(CrO_4) = 2\ Ag_2O + Sm_2O_3 + Cr_2O_3$	-2406
$2\ Gd + 2\ Ag_2(CrO_4) = 2\ Ag_2O + Gd_2O_3 + Cr_2O_3$	-2398

Table 33 (cont.)

Reaction	Enthalpy, cal/cc
$4\ Ca + 2\ Pb(CrO_4) = Pb_2O + 4\ CaO + Cr_2O_3$	-2393
$3\ Zr + 4\ Ag_2(CrO_4) = 4\ Ag_2O + 3\ ZrO_2 + 2\ Cr_2O_3$	-2377
$8\ Ta + 10\ Pb(CrO_4) = 5\ Pb_2O + 4\ Ta_2O_5 + 5\ Cr_2O_3$	-2377
$2\ Ce + 2\ Ag_2(CrO_4) = 2\ Ag_2O + Ce_2O_3 + Cr_2O_3$	-2371
$3\ Mg + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ MgO + Cr_2O_3$	-2348
$2\ Sc + 2\ Ag_2(CrO_4) = 2\ Ag_2O + Sc_2O_3 + Cr_2O_3$	-2306
$3\ Be + 2\ Ba(CrO_4) = 2\ BaO + 3\ BeO + Cr_2O_3$	-2293
$3\ Np + 4\ Ag_2(CrO_4) = 4\ Ag_2O + 3\ NpO_2 + 2\ Cr_2O_3$	-2265
$2\ Ti + 2\ Ag_2(CrO_4) = 2\ Ag_2O + Ti_2O_3 + Cr_2O_3$	-2233
$8\ Li + 2\ Pb(CrO_4) = Pb_2O + 4\ Li_2O + Cr_2O_3$	-2203
$2\ Nb + 2\ Pb(CrO_4) = Pb_2O + Nb_2O_4 + Cr_2O_3$	-2197
$8\ V + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ V_2O_3 + 3\ Cr_2O_3$	-2170
$2\ Er + 2\ Ag_2(CrO_4) = 2\ Ag_2O + Er_2O_3 + Cr_2O_3$	-2113
$3\ Ca + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ CaO + Cr_2O_3$	-2044
$3\ Th + 4\ Ba(CrO_4) = 4\ BaO + 3\ ThO_2 + 2\ Cr_2O_3$	-2030
$3\ Be + 2\ Na_2(CrO_4) = 2\ Na_2O + 3\ BeO + Cr_2O_3$	-2022
$8\ Cr + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Cr_2O_3 + 3\ Cr_2O_3$	-2011
$2\ La + 2\ Ba(CrO_4) = 2\ BaO + La_2O_3 + Cr_2O_3$	-1976
$3\ Hf + 4\ Ba(CrO_4) = 4\ BaO + 3\ HfO_2 + 2\ Cr_2O_3$	-1966
$2\ Tb + 2\ Ba(CrO_4) = 2\ BaO + Tb_2O_3 + Cr_2O_3$	-1927
$2\ Nd + 2\ Ba(CrO_4) = 2\ BaO + Nd_2O_3 + Cr_2O_3$	-1915
$2\ Pr + 2\ Ba(CrO_4) = 2\ BaO + Pr_2O_3 + Cr_2O_3$	-1912
$4\ Mn + 2\ Pb(CrO_4) = Pb_2O + 4\ MnO + Cr_2O_3$	-1904
$2\ Sm + 2\ Ba(CrO_4) = 2\ BaO + Sm_2O_3 + Cr_2O_3$	-1897
$6\ Li + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ Li_2O + Cr_2O_3$	-1894
$4\ Sr + 2\ Pb(CrO_4) = Pb_2O + 4\ SrO + Cr_2O_3$	-1894
$2\ Gd + 2\ Ba(CrO_4) = 2\ BaO + Gd_2O_3 + Cr_2O_3$	-1890
$2\ Ce + 2\ Ba(CrO_4) = 2\ BaO + Ce_2O_3 + Cr_2O_3$	-1870
$6\ Ta + 10\ Ag_2(CrO_4) = 10\ Ag_2O + 3\ Ta_2O_5 + 5\ Cr_2O_3$	-1861
$3\ Zr + 4\ Ba(CrO_4) = 4\ BaO + 3\ ZrO_2 + 2\ Cr_2O_3$	-1799
$2\ Sc + 2\ Ba(CrO_4) = 2\ BaO + Sc_2O_3 + Cr_2O_3$	-1782

Table 33 (cont.)

Reaction	Enthalpy, cal/cc
$2\ La + 2\ Na_2(CrO_4) = 2\ Na_2O + La_2O_3 + Cr_2O_3$	-1768
$6\ Nb + 8\ Ag_2(CrO_4) = 8\ Ag_2O + 3\ Nb_2O_4 + 4\ Cr_2O_3$	-1749
$2\ V + 2\ Ag_2(CrO_4) = 2\ Ag_2O + V_2O_3 + Cr_2O_3$	-1732
$3\ Hf + 4\ Na_2(CrO_4) = 4\ Na_2O + 3\ HfO_2 + 2\ Cr_2O_3$	-1722
$8\ Ga + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Ga_2O_3 + 3\ Cr_2O_3$	-1711
$2\ Nd + 2\ Na_2(CrO_4) = 2\ Na_2O + Nd_2O_3 + Cr_2O_3$	-1705
$2\ Sm + 2\ Na_2(CrO_4) = 2\ Na_2O + Sm_2O_3 + Cr_2O_3$	-1684
$2\ Gd + 2\ Na_2(CrO_4) = 2\ Na_2O + Gd_2O_3 + Cr_2O_3$	-1679
$3\ Np + 4\ Ba(CrO_4) = 4\ BaO + 3\ NpO_2 + 2\ Cr_2O_3$	-1677
$3\ Sr + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ SrO + Cr_2O_3$	-1676
$2\ Al + 2\ Na_2(CrO_4) = 2\ Na_2O + Al_2O_3 + Cr_2O_3$	-1665
$8\ P + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ P_2O_3 + 3\ Cr_2O_3$	-1658
$2\ Ti + 2\ Ba(CrO_4) = 2\ BaO + Ti_2O_3 + Cr_2O_3$	-1649
$4\ Ba + 2\ Pb(CrO_4) = Pb_2O + 4\ BaO + Cr_2O_3$	-1614
$2\ Sc + 2\ Na_2(CrO_4) = 2\ Na_2O + Sc_2O_3 + Cr_2O_3$	-1570
$4\ Zn + 2\ Pb(CrO_4) = Pb_2O + 4\ ZnO + Cr_2O_3$	-1566
$3\ Zr + 4\ Na_2(CrO_4) = 4\ Na_2O + 3\ ZrO_2 + 2\ Cr_2O_3$	-1565
$3\ Mn + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ MnO + Cr_2O_3$	-1561
$3\ Ba + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ BaO + Cr_2O_3$	-1460
$2\ Ga + 2\ Ag_2(CrO_4) = 2\ Ag_2O + Ga_2O_3 + Cr_2O_3$	-1426
$2\ P + 2\ Ag_2(CrO_4) = 2\ Ag_2O + P_2O_3 + Cr_2O_3$	-1407
$3\ Zn + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ ZnO + Cr_2O_3$	-1330
$4\ W + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ WO_3 + 3\ Cr_2O_3$	-1329
$3\ Sr + 2\ Ba(CrO_4) = 2\ BaO + 3\ SrO + Cr_2O_3$	-1296
$3\ Fe + 2\ Pb(CrO_4) = Pb_2O + Fe_3O_4 + Cr_2O_3$	-1230
$2\ Sn + 2\ Pb(CrO_4) = Pb_2O + 2\ SnO_2 + Cr_2O_3$	-1206
$2\ Mo + 2\ Pb(CrO_4) = Pb_2O + 2\ MoO_2 + Cr_2O_3$	-1198
$3\ Sr + 2\ Na_2(CrO_4) = 2\ Na_2O + 3\ SrO + Cr_2O_3$	-1162
$W + 2\ Ag_2(CrO_4) = 2\ Ag_2O + WO_3 + Cr_2O_3$	-1136
$2\ Al + 2\ K_2(CrO_4) = 2\ K_2O + Al_2O_3 + Cr_2O_3$	-1113

Table 33 (cont.)

Reaction	Enthalpy, cal/cc
$2\ Ge + 2\ Pb(CrO_4) = Pb_2O + 2\ GeO_2 + Cr_2O_3$	-1095
$9\ Fe + 8\ Ag_2(CrO_4) = 8\ Ag_2O + 3\ Fe_3O_4 + 4\ Cr_2O_3$	-1076
$3\ Sn + 4\ Ag_2(CrO_4) = 4\ Ag_2O + 3\ SnO_2 + 2\ Cr_2O_3$	-1068
$3\ Ge + 4\ Ag_2(CrO_4) = 4\ Ag_2O + 3\ GeO_2 + 2\ Cr_2O_3$	-986
$3\ Ni + 2\ Pb(CrO_4) = 2\ PbO + 3\ NiO + Cr_2O_3$	-933
$3\ Co + 2\ Pb(CrO_4) = 2\ PbO + 3\ CoO + Cr_2O_3$	-903
$3\ Ni + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ NiO + Cr_2O_3$	-865
$3\ Cd + 2\ Pb(CrO_4) = 2\ PbO + 3\ CdO + Cr_2O_3$	-859
$3\ Cd + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ CdO + Cr_2O_3$	-806
$4\ Sb + 4\ Pb(CrO_4) = 4\ PbO + Sb_4O_6 + 2\ Cr_2O_3$	-773
$2\ As + 2\ Pb(CrO_4) = 2\ PbO + As_2O_3 + Cr_2O_3$	-739
$3\ Pb + 2\ Pb(CrO_4) = 2\ PbO + 3\ PbO + Cr_2O_3$	-611
$3\ Bi + 2\ Pb(CrO_4) = 2\ PbO + 3\ BiO + Cr_2O_3$	-533
$3\ Te + 4\ Pb(CrO_4) = 4\ PbO + 3\ TeO_2 + 2\ Cr_2O_3$	-417
$3\ Te + 4\ Ag_2(CrO_4) = 4\ Ag_2O + 3\ TeO_2 + 2\ Cr_2O_3$	-407
$3\ Cu + 2\ Pb(CrO_4) = 2\ PbO + 3\ CuO + Cr_2O_3$	-406
$6\ Rb + 2\ Pb(CrO_4) = 2\ PbO + 3\ Rb_2O + Cr_2O_3$	-401
$6\ Rb + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ Rb_2O + Cr_2O_3$	-399
$S + 2\ Pb(CrO_4) = 2\ PbO + SO_3 + Cr_2O_3$	-370
$6\ Cs + 2\ Pb(CrO_4) = 2\ PbO + 3\ Cs_2O + Cr_2O_3$	-315
$6\ Tl + 2\ Pb(CrO_4) = 2\ PbO + 3\ Tl_2O + Cr_2O_3$	-314
$6\ Rb + 2\ Ba(CrO_4) = 2\ BaO + 3\ Rb_2O + Cr_2O_3$	-202
$6\ Rb + 2\ Na_2(CrO_4) = 2\ Na_2O + 3\ Rb_2O + Cr_2O_3$	-154
$6\ Rb + 2\ K_2(CrO_4) = 2\ K_2O + 3\ Rb_2O + Cr_2O_3$	-38

Table 34

MOST ENERGETIC CHROMATE AND DICHROMATE REACTIONS WITH METALS, IN TERMS OF GRAVIMETRIC ENTHALPY

Reaction	Enthalpy, cal/g
$3\ Be + 2\ Na_2(CrO_4) = 2\ Na_2O + 3\ Beo + Cr_2O_3$	-772
$4\ Be + 2\ Pb(CrO_4) = Pb_2O + 4\ BeO + Cr_2O_3$	-687
$8\ Li + 2\ Pb(CrO_4) = Pb_2O + 4\ Li_2O + Cr_2O_3$	-648
$4\ Mg + 2\ Pb(CrO_4) = Pb_2O + 4\ MgO + Cr_2O_3$	-619
$2\ Al + 2\ Na_2(CrO_4) = 2\ Na_2O + Al_2O_3 + Cr_2O_3$	-614
$4\ Ca + 2\ Pb(CrO_4) = Pb_2O + 4\ CaO + Cr_2O_3$	-611
$2\ Sc + 2\ Na_2(CrO_4) = 2\ Na_2O + Sc_2O_3 + Cr_2O_3$	-590
$8\ Sc + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Sc_2O_3 + 3\ Cr_2O_3$	-565
$3\ Be + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ BeO + Cr_2O_3$	-553
$3\ Be + 2\ Ba(CrO_4) = 2\ BaO + 3\ BeO + Cr_2O_3$	-546
$6\ Li + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ Li_2O + Cr_2O_3$	-526
$3\ Ca + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ CaO + Cr_2O_3$	-509
$3\ Mg + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ MgO + Cr_2O_3$	-509
$8\ La + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ La_2O_3 + 3\ Cr_2O_3$	-487
$2\ Zr + 2\ Pb(CrO_4) = Pb_2O + 2\ ZrO_2 + Cr_2O_3$	-484
$8\ Ti + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Ti_2O_3 + 3\ Cr_2O_3$	-484
$2\ La + 2\ Na_2(CrO_4) = 2\ Na_2O + La_2O_3 + Cr_2O_3$	-484
$3\ Zr + 4\ Na_2(CrO_4) = 4\ Na_2O + 3\ ZrO_2 + 2\ Cr_2O_3$	-478
$2\ Sc + 2\ Ag_2(CrO_4) = 2\ Ag_2O + Sc_2O_3 + Cr_2O_3$	-471
$8\ Pr + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Pr_2O_3 + 3\ Cr_2O_3$	-467
$8\ Nd + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Nd_2O_3 + 3\ Cr_2O_3$	-460
$8\ Ce + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Ce_2O_3 + 3\ Cr_2O_3$	-456
$4\ Sr + 2\ Pb(CrO_4) = Pb_2O + 4\ SrO + Cr_2O_3$	-451
$2\ Nd + 2\ Na_2(CrO_4) = 2\ Na_2O + Nd_2O_3 + Cr_2O_3$	-449
$8\ Er + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Er_2O_3 + 3\ Cr_2O_3$	-448
$8\ Ho + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Ho_2O_3 + 3\ Cr_2O_3$	-446
$2\ Sc + 2\ Ba(CrO_4) = 2\ BaO + Sc_2O_3 + Cr_2O_3$	-443
$8\ Sm + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Sm_2O_3 + 3\ Cr_2O_3$	-443
$3\ Sr + 2\ Na_2(CrO_4) = 2\ Na_2O + 3\ SrO + Cr_2O_3$	-437

Table 34 (cont.)

Reaction	Enthalpy, cal/g
$8\,Tb + 6\,Pb(CrO_4) = 3\,Pb_2O + 4\,Tb_2O_3 + 3\,Cr_2O_3$	-437
$8\,Gd + 6\,Pb(CrO_4) = 3\,Pb_2O + 4\,Gd_2O_3 + 3\,Cr_2O_3$	-435
$2\,Sm + 2\,Na_2(CrO_4) = 2\,Na_2O + Sm_2O_3 + Cr_2O_3$	-427
$2\,La + 2\,Ag_2(CrO_4) = 2\,Ag_2O + La_2O_3 + Cr_2O_3$	-427
$2\,Hf + 2\,Pb(CrO_4) = Pb_2O + 2\,HfO_2 + Cr_2O_3$	-427
$2\,Th + 2\,Pb(CrO_4) = Pb_2O + 2\,ThO_2 + Cr_2O_3$	-422
$2\,Gd + 2\,Na_2(CrO_4) = 2\,Na_2O + Gd_2O_3 + Cr_2O_3$	-418
$3\,Zr + 4\,Ag_2(CrO_4) = 4\,Ag_2O + 3\,ZrO_2 + 2\,Cr_2O_3$	-413
$2\,Pr + 2\,Ag_2(CrO_4) = 2\,Ag_2O + Pr_2O_3 + Cr_2O_3$	-410
$2\,Ti + 2\,Ag_2(CrO_4) = 2\,Ag_2O + Ti_2O_3 + Cr_2O_3$	-409
$2\,Al + 2\,K_2(CrO_4) = 2\,K_2O + Al_2O_3 + Cr_2O_3$	-408
$3\,Hf + 4\,Na_2(CrO_4) = 4\,Na_2O + 3\,HfO_2 + 2\,Cr_2O_3$	-406
$2\,Nd + 2\,Ag_2(CrO_4) = 2\,Ag_2O + Nd_2O_3 + Cr_2O_3$	-405
$2\,Ce + 2\,Ag_2(CrO_4) = 2\,Ag_2O + Ce_2O_3 + Cr_2O_3$	-401
$2\,Er + 2\,Ag_2(CrO_4) = 2\,Ag_2O + Er_2O_3 + Cr_2O_3$	-398
$2\,La + 2\,Ba(CrO_4) = 2\,BaO + La_2O_3 + Cr_2O_3$	-397
$3\,Sr + 2\,Ag_2(CrO_4) = 2\,Ag_2O + 3\,SrO + Cr_2O_3$	-396
$2\,Ho + 2\,Ag_2(CrO_4) = 2\,Ag_2O + Ho_2O_3 + Cr_2O_3$	-396
$2\,Sm + 2\,Ag_2(CrO_4) = 2\,Ag_2O + Sm_2O_3 + Cr_2O_3$	-391
$2\,Tb + 2\,Ag_2(CrO_4) = 2\,Ag_2O + Tb_2O_3 + Cr_2O_3$	-388
$2\,Gd + 2\,Ag_2(CrO_4) = 2\,Ag_2O + Gd_2O_3 + Cr_2O_3$	-386
$2\,U + 2\,Pb(CrO_4) = Pb_2O + 2\,UO_2 + Cr_2O_3$	-379
$2\,Pr + 2\,Ba(CrO_4) = 2\,BaO + Pr_2O_3 + Cr_2O_3$	-378
$3\,Th + 4\,Ag_2(CrO_4) = 4\,Ag_2O + 3\,ThO_2 + 2\,Cr_2O_3$	-377
$3\,Hf + 4\,Ag_2(CrO_4) = 4\,Ag_2O + 3\,HfO_2 + 2\,Cr_2O_3$	-377
$3\,Zr + 4\,Ba(CrO_4) = 4\,BaO + 3\,ZrO_2 + 2\,Cr_2O_3$	-374
$2\,Nd + 2\,Ba(CrO_4) = 2\,BaO + Nd_2O_3 + Cr_2O_3$	-372
$2\,Ce + 2\,Ba(CrO_4) = 2\,BaO + Ce_2O_3 + Cr_2O_3$	-367
$2\,Ti + 2\,Ba(CrO_4) = 2\,BaO + Ti_2O_3 + Cr_2O_3$	-366
$3\,Sr + 2\,Ba(CrO_4) = 2\,BaO + 3\,SrO + Cr_2O_3$	-360
$2\,Sm + 2\,Ba(CrO_4) = 2\,BaO + Sm_2O_3 + Cr_2O_3$	-356

Table 34 (cont.)

Reaction	Enthalpy, cal/g
$2\ Tb + 2\ Ba(CrO_4) = 2\ BaO + Tb_2O_3 + Cr_2O_3$	-352
$2\ Gd + 2\ Ba(CrO_4) = 2\ BaO + Gd_2O_3 + Cr_2O_3$	-350
$4\ Ba + 2\ Pb(CrO_4) = Pb_2O + 4\ BaO + Cr_2O_3$	-350
$8\ V + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ V_2O_3 + 3\ Cr_2O_3$	-347
$3\ U + 4\ Ag_2(CrO_4) = 4\ Ag_2O + 3\ UO_2 + 2\ Cr_2O_3$	-341
$3\ Th + 4\ Ba(CrO_4) = 4\ BaO + 3\ ThO_2 + 2\ Cr_2O_3$	-341
$3\ Hf + 4\ Ba(CrO_4) = 4\ BaO + 3\ HfO_2 + 2\ Cr_2O_3$	-337
$2\ Np + 2\ Pb(CrO_4) = Pb_2O + 2\ NpO_2 + Cr_2O_3$	-336
$8\ P + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ P_2O_3 + 3\ Cr_2O_3$	-336
$2\ Nb + 2\ Pb(CrO_4) = Pb_2O + Nb_2O_4 + Cr_2O_3$	-328
$3\ Ba + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ BaO + Cr_2O_3$	-320
$8\ Cr + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Cr_2O_3 + 3\ Cr_2O_3$	-312
$3\ Np + 4\ Ag_2(CrO_4) = 4\ Ag_2O + 3\ NpO_2 + 2\ Cr_2O_3$	-307
$2\ V + 2\ Ag_2(CrO_4) = 2\ Ag_2O + V_2O_3 + Cr_2O_3$	-305
$8\ Ta + 10\ Pb(CrO_4) = 5\ Pb_2O + 4\ Ta_2O_5 + 5\ Cr_2O_3$	-304
$2\ P + 2\ Ag_2(CrO_4) = 2\ Ag_2O + P_2O_3 + Cr_2O_3$	-294
$4\ Mn + 2\ Pb(CrO_4) = Pb_2O + 4\ MnO + Cr_2O_3$	-292
$6\ Nb + 8\ Ag_2(CrO_4) = 8\ Ag_2O + 3\ Nb_2O_4 + 4\ Cr_2O_3$	-292
$6\ Ta + 10\ Ag_2(CrO_4) = 10\ Ag_2O + 3\ Ta_2O_5 + 5\ Cr_2O_3$	-277
$8\ Ga + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ Ga_2O_3 + 3\ Cr_2O_3$	-275
$3\ Mn + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ MnO + Cr_2O_3$	-265
$3\ Np + 4\ Ba(CrO_4) = 4\ BaO + 3\ NpO_2 + 2\ Cr_2O_3$	-258
$2\ Ga + 2\ Ag_2(CrO_4) = 2\ Ag_2O + Ga_2O_3 + Cr_2O_3$	-251
$4\ Zn + 2\ Pb(CrO_4) = Pb_2O + 4\ ZnO + Cr_2O_3$	-240
$3\ Zn + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ ZnO + Cr_2O_3$	-225
$3\ Fe + 2\ Pb(CrO_4) = Pb_2O + Fe_3O_4 + Cr_2O_3$	-187
$2\ Sn + 2\ Pb(CrO_4) = Pb_2O + 2\ SnO_2 + Cr_2O_3$	-184
$9\ Fe + 8\ Ag_2(CrO_4) = 8\ Ag_2O + 3\ Fe_3O_4 + 4\ Cr_2O_3$	-182
$3\ Sn + 4\ Ag_2(CrO_4) = 4\ Ag_2O + 3\ SnO_2 + 2\ Cr_2O_3$	-180
$2\ Ge + 2\ Pb(CrO_4) = Pb_2O + 2\ GeO_2 + Cr_2O_3$	-179
$3\ Ge + 4\ Ag_2(CrO_4) = 4\ Ag_2O + 3\ GeO_2 + 2\ Cr_2O_3$	-176
$2\ Mo + 2\ Pb(CrO_4) = Pb_2O + 2\ MoO_2 + Cr_2O_3$	-173

Table 34 (cont.)

Reaction	Enthalpy, cal/g
$4\ W + 6\ Pb(CrO_4) = 3\ Pb_2O + 4\ WO_3 + 3\ Cr_2O_3$	-171
$1\ W + 2\ Ag_2(CrC_4) = 2\ Ag_2O + WO_3 + Cr_2O_3$	-170
$6\ Rb + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ Rb_2O + Cr_2O_3$	-153
$6\ Rb + 2\ Pb(CrO_4) = 2\ PbO + 3\ Rb_2O + Cr_2O_3$	-151
$3\ Ni + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ NiO + Cr_2O_3$	-141
$3\ Ni + 2\ Pb(CrO_4) = 2\ PbO + 3\ NiO + Cr_2O_3$	-138
$3\ Co + 2\ Pb(CrO_4) = 2\ PbO + 3\ CoO + Cr_2O_3$	-134
$3\ Cd + 2\ Ag_2(CrO_4) = 2\ Ag_2O + 3\ CdO + Cr_2O_3$	-126
$3\ Cd + 2\ Pb(CrO_4) = 2\ PbO + 3\ CdO + Cr_2O_3$	-123
$4\ Sb + 4\ Pb(CrO_4) = 4\ PbO + Sb_4O_6 + 2\ Cr_2O_3$	-120
$2\ As + 2\ Pb(CrO_4) = 2\ PbO + As_2O_3 + Cr_2O_3$	-119
$6\ Cs + 2\ Pb(CrO_4) = 2\ PbO + 3\ Cs_2O + Cr_2O_3$	-115
$6\ Rb + 2\ Ba(CrO_4) = 2\ BaO + 3\ Rb_2O + Cr_2O_3$	-88
$6\ Rb + 2\ Na_2(CrO_4) = 2\ Na_2O + 3\ Rb_2O + Cr_2O_3$	-83
$3\ Pb + 2\ Pb(CrO_4) = 2\ PbO + 3\ PbO + Cr_2O_3$	-75
$3\ Te + 4\ Ag_2(CrO_4) = 4\ Ag_2O + 3\ TeO_2 + 2\ Cr_2O_3$	-70
$3\ Bi + 2\ Pb(CrO_4) = 2\ PbO + 3\ BiO + Cr_2O_3$	-69
$3\ Te + 4\ Pb(CrO_4) = 4\ PbO + 3\ TeO_2 + 2\ Cr_2O_3$	-66
$S + 2\ Pb(CrO_4) = 2\ PbO + SO_3 + Cr_2O_3$	-64
$3\ Cu + 2\ Pb(CrO_4) = 2\ PbO + 3\ CuO + Cr_2O_3$	-60
$6\ Tl + 2\ Pb(CrO_4) = 2\ PbO + 3\ Tl_2O + Cr_2O_3$	-34
$6\ Rb + 2\ K_2(CrO_4) = 2\ K_2O + 3\ Rb_2O + Cr_2O_3$.	-20

Table 35

VOLUMETRIC ENTHALPIES (cal/cc) OF REACTIONS OF METALS WITH CHROMATES AND DICHROMATES
(In descending order from top to bottom and left to right)

Metal	$PbCrO_4$	Ag_2CrO_4	$BaCrO_4$	Na_2CrO_4	K_2CrO_4
Be	-3845	-2881	-2293	-2022	
U	-3322	-2546			
Hf	-3310	-2543	-1966	-1722	
Th	-3259	-2563	-2030		
Ho	-3173	-2529			
Zr	-3065	-2377	-1799	-1565	
Tb	-3048	-2439	-1927		
La	-3046	-2464	-1976	-1768	
Sm	-2999	-2406	-1897	-1684	
Nd	-2998	-2415	-1915	-1705	
Gd	-2986	-2398	-1890	-1679	
Pr	-2980	-2408	-1912		
Ce	-2939	-2371	-1870		
Np	-2914	-2265	-1677		
Mg	-2907	-2348			
Sc	-2879	-2305	-1782	-1570	
Ti	-2861	-2233	-1649		
Er	-2499	-2113			
Ca	-2393	-2044			
Ta	-2377	-1861			
Li	-2203	-1894			
Nb	-2197	-1749			
V	-2170	-1732			
Cr	-2011				
Mn	-1904	-1561			
Sr	-1894	-1676	-1296	-1162	
Al				-1665	-1113
P	-1658	-1407			
Ba	-1614	-1460			
Zn	-1566	-1330			
Ga	-1711	-1426			
W	-1329	-1136			
Fe	-1230	-1076			
Sn	-1206	-1068			
Mo	-1198				
Ge	-1095	-986			
Ni	-933	-865			
Co	-903				
Cd	-859	-806			
Sb	-773				
As	-739				
Pb	-611				
Bi	-533				
Te	-417	-407			
Cu	-406				
Rb	-401	-399	-202	-154	-38
S	-370				
Cs	-315				
Tl	-314				

Table 36

GRAVIMETRIC ENTHALPIES (cal/g) OF REACTIONS OF METALS WITH CHROMATES AND DICHROMATES
(In descending order from top to bottom and left to right)

Metal	Na_2CrO_4	$PbCrO_4$	Ag_2CrO_4	$BaCrO_4$	K_2CrO_4
Be	-772	-687	-553	-546	
Li		-648	-526		
Mg		-619	-509		
Al	-614				-408
Ca		-611	-509		
Sc	-590	-565	-471	-443	
La	-484	-487	-427	-397	
Zr	-478	-484	-413	-374	
Ti		-484	-409	-366	
Pr		-467	-410	-378	
Nd	-449	-460	-405	-372	
Ce		-456	-401	-367	
Sr	-437	-451	-396	-360	
Er		-448	-398		
Ho		-446	-396		
Sm	-427	-443	-391	-356	
Tb		-437	-388	-352	
Gd	-418	-435	-386	-350	
Hf	-406	-427	-377	-337	
Th		-422	-377	-341	
U		-379	-341		
Ba		-350	-320		
V		-347	-305		
Np		-336	-307	-258	
P		-336	-294		
Nb		-328	-292		
Cr		-312			
Ta		-304	-277		
Mn		-292	-265		
Ga		-275	-251		
Zn		-240	-225		
Fe		-187	-182		
Sn		-184	-180		
Ge		-179	-176		
Mo		-173			
W		-171	-170		
Rb	-83	-151	-153	-88	-20
Ni		-138	-141		
Co		-134			
Cd		-123	-126		
Sb		-120			
As		-119			
Cs		-115			
Pb		-75			
Te		-66	-70		
Bi		-69			
S		-64			
Cu		-60			
Tl		-34			

K. Boride Reactions

The reactions of 3 metals with 8 borides resulted in 14 reactions. Although the properties for only a few reactions were calculated, they are of interest because of the refractory nature of the products and reactants. Some representative reactions are shown in Table 37, and the volumetric and gravimetric enthalpies of all the boride reactions are listed in Tables 38 and 39. Except for boron carbide, the enthalpies are low. However, the reactions of titanium and zirconium with boron carbide are energetic. It would be interesting to examine these reactions experimentally to determine the effect of the refractoriness of the reactants and products on the behavior of the reactions.

Table 37

DATA ON REACTIONS OF VARIOUS METALS WITH BORIDES

	4 N	+	CB_4	=	C	+	4 NB
Heat of formation			12.20				60.30
Molecular weight	14.01		55.29		12.01		24.83
Density	.81		2.50		2.25		2.20
Melting point, °C			2450.00				3000.00
Boiling point, °C			3500.00		4347.00		
Heat of reaction, kcal	-229.00						
Reactants' density	1.22						
Gravimetric enthalpy, cal/g	-2057.10						
Volumetric enthalpy, cal/cc	-2503.76						

	2 Ti	+	CB_4	=	C	+	2 TiB_2
Heat of formation			12.20				70.00
Molecular weight	47.90		55.29		12.01		69.54
Density	4.50		2.50		2.25		4.5
Melting point, °C	1812.00		2450.00				
Boiling point, °C	3000.00		3500.00		4347.00		
Heat of reaction, kcal	-127.80						
Reactants' density	3.48						
Gravimetric enthalpy, cal/g	-845.85						
Volumetric enthalpy, cal/cc	-2944.37						

	2 Zr	+	CB_4	=	C	+	2 ZrB_2
Heat of formation			12.20				76.40
Molecular weight	91.22		55.29		12.01		112.86
Density	6.40		2.50		2.25		6.08
Melting point, °C	1852.00		2450.00				
Boiling point, °C	2900.00		3500.00		4347.00		
Heat of reaction, kcal	-140.60						
Reactants' density	4.70						
Gravimetric enthalpy, cal/g	-591.43						
Volumetric enthalpy, cal/cc	-2777.43						

Table 37 (cont.)

	$2\ N$	+	TiB_2	=	Ti	+	$2\ NB$
Heat of formation			70.00				-60.30
Molecular weight	14.01		69.54		47.90		24.83
Density	.81		4.5		4.50		2.20
Melting point, °C					1812.00		3000.00
Boiling point, °C					3000.00		
Heat of reaction, kcal	-50.60						
Reactants' density	1.95						
Gravimetric enthalpy, cal/g	-518.68						
Volumetric enthalpy, cal/cc	-1010.97						

	$5\ N$	+	Ti_2B_5	=	$2\ Ti$	+	$5\ NB$
Heat of formation			-105.00				-60.30
Molecular weight	14.01		149.90		47.90		24.83
Density	.81		4.63		4.50		2.20
Melting point, °C					1812.00		3000.00
Boiling point, °C					3000.00		
Heat of reaction, kcal	-196.50						
Reactants' density	1.85						
Gravimetric enthalpy, cal/g	-893.43						
Volumetric enthalpy, cal/cc	-1650.44						

	$5\ Zr$	+	$2\ Ti_2B_5$	=	$4\ Ti$	+	$5\ ZrB_2$
Heat of formation			-105.00				-76.40
Molecular weight	91.22		149.90		47.90		112.86
Density	6.40		4.63		4.50		6.08
Melting point, °C	1852.00				1812.00		
Boiling point, °C	2900.00				3000.00		
Heat of reaction, kcal	-172.00						
Reactants' density	5.56						
Gravimetric enthalpy, cal/g	-227.54						
Volumetric enthalpy, cal/cc	-1264.55						

Table 38

VOLUMETRIC ENTHALPIES (cal/cc) OF REACTIONS OF METALS WITH BORIDES
(In descending order from top to bottom and left to right)

Metal	CB_4	Ti_2B_5	TiB_2	ZrB_2	TiB
Ti	-2944				
N	-2503	-1650	-1037	- 830	- 804
Zr	-2777	-1264	- 221		- 110

Table 39

GRAVIMETRIC ENTHALPIES (cal/g) OF REACTIONS OF METALS WITH BORIDES
(In descending order from top to bottom and left to right)

Metal	CB_4	ZrB_2	Ti_2B_5	TiB_2	TiB	ZrB_2	Ti_2B	ZrB
N	-2057	-1551	- 893	- 518	- 334	- 313	- 201	- 183
Ti	- 845	- 277			- 20			
Zr	- 591		- 227	- 39				

L. Phosphide Reactions

A total of 25 phosphides and 500 reactions was surveyed. The phosphides do not form an energetic class of reactions. The most energetic revealed in these studies,

$$15\ Mg + 2\ N_3P_5 = 6\ N + 5\ Mg_3P_2,$$

yields only -1439 cal/cc. A few representative reactions are shown in Table 40.

Table 40

DATA ON REACTIONS OF VARIOUS METALS WITH PHOSPHIDES

	9 Mg	+	2 Au_2P_3	=	4 Au	+	3 Mg_3P_2
Heat of formation			-24.10				-128.00
Molecular weight	24.32		487.34		197.00		134.91
Density	1.74		6.67		19.30		
Melting point, °C	650.00				1063.00		
Boiling point, °C	1120.00				2660.00		
Heat of reaction, kcal	-335.80						
Reactants' density	4.39						
Gravimetric enthalpy, cal/g	-281.34						
Volumetric enthalpy, cal/cc	-1254.91						

	3 Mg	+	Ba_3P_2	=	3 Ba	+	Mg_3P_2
Heat of formation			-118.00				-128.00
Molecular weight	24.32		474.03		137.36		134.91
Density	1.74				3.50		
Melting point, °C	650.00				704.00		
Boiling point, °C	1120.00				1638.00		
Heat of reaction, kcal	-10.00						
Reactants' density							
Gravimetric enthalpy, cal/g	-18.28						
Volumetric enthalpy, cal/cc							

	3 Mg	+	Ca_3P_2	=	3 Ca	+	Mg_3P_2
Heat of formation			-120.50				-128.00
Molecular weight	24.32		182.20		40.08		134.91
Density	1.74		2.24		1.55		
Melting point, °C	650.00		1600.00		850.00		
Boiling point, °C	1120.00				1240.00		
Heat of reaction, kcal	-7.50						
Reactants' density	2.07						
Gravimetric enthalpy, cal/g	-29.39						
Volumetric enthalpy, cal/cc	-60.81						

Table 40 (cont.)

	3 Mg	+	2 Cu_3P	=	6 Cu	+	Mg_3P_2
Heat of formation			-36.40				-128.00
Molecular weight	24.32		221.60		63.54		134.91
Density	1.74		6.40		8.92		
Melting point, °C	650.00				1083.00		
Boiling point, °C	1120.00				2582.00		
Heat of reaction, kcal	-55.20						
Reactants' density	4.64						
Gravimetric enthalpy, cal/g	-106.94						
Volumetric enthalpy, cal/cc	-496.49						

	3 Mg	+	CuP_2	=	Cu	+	Mg_3P_2
Heat of formation			-28.90				-128.00
Molecular weight	24.32		125.49		63.54		134.91
Density	1.74				8.92		
Melting point, °C	650.00				1083.00		
Boiling point, °C	1120.00				2582.00		
Heat of reaction, kcal	-99.10						
Reactants' density							
Gravimetric enthalpy, cal/g	-499.37						
Volumetric enthalpy, cal/cc							

	3 Mg	+	2 FeP	=	2 Fe	+	Mg_3P_2
Heat of formation			-28.00				-128.00
Molecular weight	24.32		86.83		55.85		134.91
Density	1.74		5.20		7.86		
Melting point, °C	650.00				1535.00		
Boiling point, °C	1120.00				2800.00		
Heat of reaction, kcal	-72.00						
Reactants' density	3.27						
Gravimetric enthalpy, cal/g	-291.95						
Volumetric enthalpy, cal/cc	-955.83						

M. Organic Fluoride Reactions

A limited survey was made of the reactions of organic fluorides with metals. The properties were tabulated for 76 organic fluorides for which data on heat of formation were available. These included perfluorinated compounds, partially fluorinated hydrocarbons, mixed halogenated organics, and organics containing various combinations of hydrogen, oxygen, nitrogen and fluorine. The enthalpies of reactions of 89 metals* with carbon tetrafluoride and hexafluoroethane were calculated. Both of these compounds are effective oxidizers.

The volumetric enthalpies for the 30 most energetic reactions of each fluoride are listed in Tables 41 and 42. Each reaction is represented by the metal reactant and the product fluoride. The Group IIA metals (beryllium, magnesium, calcium, strontium, and barium), the Group IVB metals (titanium, zirconium, and hafnium), and the rare earth metals (yttrium, lanthanum, neodymium, praseodymium, uranium, and thorium) are very energetic with these fluorides.

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*In this instance each valence state of a metal is considered as a separate unit.

Table 41

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH ORGANIC FLUORIDES C_2F_6

Reaction	Product	Enthalpy, cal/cc
Be	BeF_2	-5.75
Y	YF_3	-5.14
La	LaF_3	-5.02
Nd	NdF_3	-4.98
Pr	PrF_3	-4.97
U	UF_3	-4.74
Mg	MgF_2	-4.73
Hf	HfF_3	-4.54
U	UF_4	-4.53
Th	ThF_4	-4.50
Sc	ScF_3	-4.47
Zr	ZrF_3	-4.46
Zr	ZrF_4	-4.45
Hf	HfF_4	-4.36
Li	LiF	-4.18
Ca	CaF_2	-4.14
Ti	TiF_3	-4.07
Th	ThF_3	-4.05
Ce	CeF_3	-4.05
Al	AlF_3	-4.04
Hf	HfF_2	-3.92
U	UF_5	-3.85
Zr	ZrF_2	-3.84
V	VF_2	-3.59
Ti	TiF_4	-3.48
B	BF_3	-3.47

Table 41 (cont.)

Reaction	Product	Enthalpy, cal/cc
Si	SiF_4	-3.42
Mn	MnF_2	-3.36
Ti	TiF_2	-3.32
Ce	CeF_4	-3.30
V	VF_3	-3.29
Cr	CrF_3	-3.26
Ba	BaF_2	-3.23
U	UF_6	-3.16
Cr	CrF_2	-3.15
Ta	TaF_3	-2.90
V	VF_4	-2.83
Zn	ZnF_2	-2.82
Ta	TaF_2	-2.80
Ga	GaF_3	-2.75
Na	NaF	-2.67
Mn	MnF_3	-2.63
Fe	FeF_3	-2.59
Ni	NiF_2	-2.53
Co	CoF_2	-2.51
In	InF_3	-2.45
Ge	GeF_2	-2.34
Cd	CdF_2	-2.25
Cr	CrF_4	-2.22
Ta	TaF_5	-2.19
Ga	GaF_2	-2.18
Cr	CrF_5	-2.16

Table 41 (cont.)

Reaction	Product	Enthalpy, cal/cc
W	WF_6	-2.09
In	InF_2	-1.97
Mo	MoF_6	-1.96
Nb	NbF_5	-1.94
V	VF_5	-1.91
Ge	GeF_4	-1.91
Sn	SnF_2	-1.89
Mo	MoF_5	-1.89
Pb	PbF_2	-1.83
Bi	BiF_4	-1.76
Sb	SbF_3	-1.75
N	NF_3	-1.70
Bi	BiF_3	-1.64
K	KF	-1.63
Mo	MoF_4	-1.62
Co	CoF_3	-1.53
W	WF_4	-1.52
Fe	FeF_2	-1.50
Sn	SnF_4	-1.50
Cu	CuF_2	-1.47
Rb	RbF	-1.34
Sb	SbF_5	-1.31
Bi	BiF_2	-1.30
Mn	MnF_4	-1.22
W	WF_5	-1.16

Table 42

VOLUMETRIC ENTHALPIES OF REACTIONS OF METALS WITH ORGANIC FLUORIDES CF_4

Reaction	Product	Enthalpy, cal/cc
Be	BeF_2	-5.14
Y	YF_3	-4.69
La	LaF_3	-4.57
Nd	NdF_3	-4.57
Pr	PrF_3	-4.51
Mg	MgF_2	-4.24
U	UF_3	-4.167
Th	ThF_4	-3.94
Sc	ScF_3	-3.93
U	UF_4	-3.90
Zr	ZrF_4	-3.83
Li	LiF	-3.82
Ca	CaF_2	-3.75
Hf	HfF_4	-3.72
Ce	CeF_3	-3.64
Th	ThF_3	-3.52
Al	AlF_3	-3.37
Sr	SrF_2	-3.23
U	UF_5	-3.14
V	VF_2	-2.93
Ba	BaF_2	-2.88
Ce	CeF_4	-2.76
Ti	TiF_4	-2.73
Si	SiF_4	-2.68
B	BF_3	-2.66
Mn	MnF_2	-2.65
V	VF_3	-2.54

Table 42 (cont.)

Reaction	Product	Enthalpy, cal/cc
Cr	CrF_3	-2.48
Cr	CrF_2	-2.42
U	UF_6	-2.36
Na	NaF	-2.33
Ta	TaF_3	-2.16
Ta	TaF_2	-2.12
Zn	ZnF_2	-2.12
Ga	GaF_3	-2.00
V	VF_4	-1.99
Mn	MnF_3	-1.80
Fe	FeF_3	-1.75
In	InF_3	-1.75
Ni	NiF_2	-1.73
Co	CoF_2	-1.71
Au	AuF	-1.71
Cd	CdF_2	-1.58
Au	AuF_3	-1.45
K	Kf	-1.41
Os	OsF_8	-1.39
Os	OsF_6	-1.35
In	InF_2	-1.33
Cr	CrF_4	-1.31
Ta	TaF_5	-1.30
Sn	SnF_2	-1.26
Pb	PbF_2	-1.22
Cr	CrF_5	-1.22
Ge	GeF_4	-1.56
Rb	RbF	-1.14

Table 42 (cont.)

Reaction	Product	Enthalpy, cal/cc
Nb	NbF_5	-1.03
Sb	SbF_3	-1.03
Mo	MoF_6	-1.01
Bi	BiF_4	-1.01
V	VF_5	-1.01
Bi	BiF_3	- .95
Mo	MoF_5	- .95
Cs	CsF	- .88
Mo	MoF_4	- .69
Sn	SnF_4	- .66
Fe	FeF_2	- .64
Cu	CuF_2	- .60
W	Wf_4	- .58
Co	CoF_3	- .58
In	InF	- .57
Sb	SbF_5	- .43
Tl	TlF	- .37
Cu	CuF	- .30
Ag	AgF	- .28

IV. ENTHALPY BEHAVIOR PATTERNS

The groups examined in the present study are compared in Table 43 according to the energy of their reactions. The most meaningful comparison would involve reactions between one metal and the compounds of another metal, e.g., the reactions of magnesium with the carbide, nitride, oxide, fluoride, silicide, phosphide, and sulfide of lithium. Because of the limited data available, however, the values in Table 43 apply to reactions of the metals with different compounds in each system. These compounds are listed at the top of each column.

Table 43

COMPARISON OF THE REACTION ENERGIES OF THE GROUPS STUDIED

	Volumetric Enthalpy, kcal/cc					
Family	Group IV	Group V		Group VI	Group VII	
2	Li_2C_2	Fe_2N	$Ba(N_3)_2$	$LiNO_3$	CoF_3	
Be	-	-2.4	-3.3	-7.8	-5.1	
Mg	0	-1.3	-1.3	-5.0	-4.1	
Al	-0.1	-1.9	-2.5	-6.4	-3.0	
Ta	-2.5	-1.8	-2.5	-5.1	-1.8	
Ba	-	-0	-	-2.2	-2.8	
Th	-0.6	-2.2	-2.6	-5.9	-3.8	
3	$CoSi_2$	N_3P_5		FeS_2	$CoCl_2$	WCl_4
Be	-	-		-2.1	-1.2	-2.2
Mg	-0.1	-1.4		-2.4	-1.5	-2.4
Al	-	-		-1.2	-1.0	-1.8
Ta	-	-		-	-	-1.1
Ba	-5.1	-		-1.4	-1.7	-2.3
Th	-	-		-3.2	-1.4	-2.4

The oxide and fluoride reactions tend to be the most energetic. The nitrates and nitrites are included in the oxide system since the reaction products are invariably oxides. The nitrides, including the more energetic azides, the chlorides, the sulfides, and the carbides, are the next most energetic, in that order. The phosphides are the least energetic. Among the metals this order is followed by the reactions of beryllium,

magnesium, aluminum, tantalum, and thorium, with minor irregularities associated with each metal. Except for the highly energetic barium silicide system, barium follows a similar order.

The silicide and chloride systems are unusual in that the heats of formation, in Group II at least, increase greatly with increasing atomic number. In the other systems the heats of formation tend to remain relatively constant or to decrease with increasing atomic number.

Although the data are limited, it appears that compounds of the elements of the second period, i.e., the carbides, nitrides, oxides, and fluorides, are more energetic than those of the third period, i.e., the phosphides and sulfides. Again, the silicides are an exception, being more energetic than the carbides.

V. RELATION OF THE DATA TO REALITY

In using or interpreting the calculated data, the stoichiometry, free energy, and kinetics associated with experimental conditions must be considered.

In almost all cases, the calculated values represent the stoichiometric reaction that has the highest calculated enthalpy. However, many of the reactant combinations can undergo, theoretically at least, several different stoichiometric reactions which produce different combinations of products. The reactions of a metal with a chlorate, for instance, may produce different combinations of oxides and chlorides; i.e., the coefficients c, d, e, and f in the following equation can have values of zero or higher in any combination that will yield a balanced equation.

$$a\,A + b\,BClO_3 \;=\; c\,AO + d\,BO + e\,BCl + F\,ACl$$

There is no way of predicting the stoichiometry of a reaction in an experimental situation. Thus, experimentally, a reaction may not yield the maximum energy outputs that were calculated. Also, the reaction mixtures that function most satisfactorily in practical applications usually deviate appreciably from the stoichiometric ratio.

Only enthalpies were considered in the present program. The enthalpy (ΔH) is of most interest for present purposes because it is a measure of the amount of heat energy liberated by a reaction at a particular temperature. Conceptually, a reaction such as

$$3\,Be + 2\,CoF_3 \;=\; 2\,Co + BeF_2 + 380.2\ \text{kcal}$$

can be considered to occur at an infinitesimal rate at 298°K and to liberate 380.2 kcal of thermal energy. This energy will be dissipated by conduction, convection, and radiation. Since radiative transfer is an inefficient process at such a low temperature, most of the energy will be lost by conduction and convection. Conversely, the reaction may be carried out under adiabatic conditions, in which case the energy liberated will be used to heat the products of the reaction to a temperature determined by the heat content of the products and by the manner in which the enthalpy, entropy, and free energy of the reaction vary with temperature.

In reality, however, these types of reactions proceed rapidly under partially adiabatic conditions after they are initiated, and the products of the reaction are heated to very high temperatures by the energy liberated. As the products cool from a high temperature to 298°K, they effectively convert a sizeable portion of the thermal energy to radiative energy. And since radiation is our primary concern, the

the enthalpy is the most significant thermodynamic quantity. Fortunately, it also is the function which is most frequently available in the literature.

The free energy (ΔF) defines the equilibrium state of a reaction and thus indicates the extent to which a reaction can occur. The free energy can be considered the enthalpy minus a correction term consisting of $T\Delta S$, where T is the temperature and ΔS is the entropy change. In most instances and especially in the present case, where large negative enthalpies are involved, the correction term is small compared with the enthalpy, and $\Delta H_{298} \sim \Delta F_{298}$, The change of the enthalpy with temperature is small because it depends on the change in heat capacity between the products and the reactants, and this change is usually small if no phase changes occur. The amount of energy liberated per mole of reaction will therefore be relatively independent of temperature. On the other hand, the free energy is strongly dependent on temperature. In fact, there is usually a temperature at which the free energy of a reaction passes through zero, indicating that the direction of the reaction has reversed. This means that although the energy output for a mole of reaction may be the same at different temperatures, the reaction will only occur to a small extent when the free energy is near zero.

Thus, although a theoretical reaction may be very energetic, it may, in fact, proceed to such a small extent that the thermal output will be greatly reduced. In a future program it may be interesting to examine the behavior of the free-energy function of some of the more interesting reactions for which free-energy data of the constituents are available.

A factor not considered but very important for practical applications is the kinetics of the reactions. There is no way of predicting the kinetics of these types of reactions. Although a reaction may be highly energetic, its kinetics may be such that the output of thermal energy is too slow to be utilized practically. In addition, these reactions must be heated to a temperature at which they can propagate at a finite rate. This temperature cannot be predicted, but is very important for practical applications and even for theoretical studies.

Because of all these unknown factors in the experimental and practical realizations of these reactions, an extensive experimental program involving several areas of study is necessary. Calorimetric studies can be used to determine the validity of the present calculations. The thermal output can be studied as a function of the stoichiometry of the reaction and the physical variations of the reactants. To further substantiate the calculations, the products of the reactions can be chemically analyzed. For theoretical and practical applications the kinetics and mechanisms of the reactions can

be studied by burning rate, radiation, and spectroscopic studies, and differential thermal analysis and thermogravimetric analysis at different stoichiometries, different ambient conditions, and different variations of the physical properties of the reactants.

In summary, the thermal data presented in this report provide a rational method for choosing reactions to be studied experimentally for theoretical and practical applications. The ancillary data included on the physical properties of the reactants and the products of each reaction aid in the selection, since these properties may be important for the theoretical and practical applications.

VI. SUMMARY

The heats of reactions of metals with oxides, nitrites, chlorates, perchlorates, chromates, chlorides, fluorides, sulfides, nitrides, azides, carbides, phosphides, and silicides were tabulated on a Univac 1105 computer. The reactions involving chlorates, oxides, nitrates, nitrites, and fluorides tend to be the most energetic. The metals associated with the highest energies released are beryllium, magnesium, aluminum, lithium, calcium, titanium, zirconium, hafnium, lanthanum, cesium, neodymium, praseodymium, thorium, and uranium. The highest energy, -9459 cal/cc, is realized by the reaction of beryllium with magnesium perchlorate.

In all, about 20,000 reactions were tabulated. Each reaction was recorded in the primary tabulation in the form of a balanced equation. This was followed by a tabulation of input data, consisting of heats of formation, molecular weight, melting and boiling points, and also output data, consisting of reaction density and heat of reaction on molar, gravimetric, and volumetric bases.

In consequence of this large amount of detail, a page of data consists of only three equations and the data are voluminous. Therefore, only the most significant results are presented in this report and the remainder summarized. The full utility of the compilation is best realized by the establishment of secondary computer programs, designed to present the data in forms to meet specific requirements. Thus, computer programs were prepared to summarize the data in each class of reactions in descending orders of volumetric and gravimetric heats of reaction. Other programs were used to present graphically the heats of the reactions of a metal with all the oxidants of a particular class or an oxidant with all the metals, on molar, volumetric, and gravimetric bases. Still other programmed tabulations show in grid form the data for all metals with oxidizers (oxides, fluorides, chlorates, etc.), arranged in order of the energy of reaction.

The tabulations of the data presented in this report were prepared to meet the requirements of a specific problem. However, the special merit of the system lies in its versatility, since the possible treatments of the data can be varied to cope with innumerable applications involving other uses of these data.

VII. FUTURE WORK

The studies presented here have been essentially completed as far as the enthalpies are concerned. Almost all systems of potential interest for which data are available are included. It would be of interest, however, to calculate the free energy and equilibria of certain reactions as a function of temperature. These calculations would predict the maximum temperature and the extent of the reactions. They would be limited to reactions for which free energy and specific heat data are available.